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ABOUT GROUND MOTION PREDICTION EQUATIONS SELECTION

Abstract. Ground motion prediction equations (GMPE) relate the strong ground motion shaking parameters to variables describing earthquake source, path, and on-site impact. From the many available GMPEs, we select those models that are suitable for use in seismic hazard assessment and take into account regional seismic and tectonic conditions. We present a GMPE selection procedure that evaluates multidimensional ground motion trends (e.g., in magnitude, distance, and structural period), examines functional forms, and evaluates quantitative GMPE performance tests versus independent data. Our recommendations include international simulation-based models for seismically active crustal regions, and models for stable regions. To approximate epistemological uncertainties, the selection process takes into account alternative representations of key GMPE attributes such as velocity attenuation over distance.

Keywords: ground motion prediction equations (GMPE), attenuation, soil motion.

Introduction. Ground motion prediction equations relate parameters of ground shaking, i.e. peak ground accelerations (PGA), spectral accelerations or velocities, with set of independent variables, describing source, wave propagation, site conditions [3]. These variables include distance from source to site, parameterization of site conditions, and type of focal mechanism. Some recent models also take into account other factors, affecting the soil rupture during the earthquakes, for example, the effect of hanging walls. For the last five decades, hundreds of GMPEs have been published to predict PGA and spectral accelerations of linear elastic reactions. Thus, scientists face the difficult task of deciding which GMPE should be used for different projects [4].

We will consider the process of international GMPEs selection, which are available in NGA, NGAEast, and NGAWest databases. The preliminary selection is based on the application of the criteria of exclusion to the full list of generalized models [5]. These quality assurance criteria exclude models that, for example, have been replaced by later GMPEs, prohibiting predictions for the entire range of interest magnitude-distance-structural period, and using independent (e.g., magnitude scale) or dependent (e.g., values of horizontal components) parameters that would complicate their usage in modern seismic assessments. As described above, the procedure of ground motion models selection require approximately three to four recommended GMPEs for each of the main tectonic regimes in practical terms, for example, the period of calculation [6]. Ideally, the choice of these GMPEs should take into account the regional differences in the modes: ASR for active seismic regimes, SSR for stable seismic regimes, MSR for moderate seismic regimes, which take the form of variable GMPE attributes, such as the velocity attenuation with a distance [7]. In this article, we describe the work done during the process of seismic hazard assessment in order to predict soil shaking parameters, to balance these competing goals in the process of selecting several relatively reliable models, which are presented in an unambiguous way [8].

Models, selected for the East Kazakhstan region within the work on seismic hazard assessment provided by the Institute of Seismology, will be shown to demonstrate the results of ground motion models selection. In this article, we pay particular attention to the selection process, which may have a long-term application even after the selected GMPE will be replaced [9].

Procedure, investigated the task of GMPE choosing, including the composition of the group of experts and information, considered in the selection process is presented in the following sections. Then, the general tools used in selection criteria, are described, i.e. trellis plots, comparing GMPE predictions for different scenarios of earthquakes, reviews of investigations, comparing calculated results of predicted and obtained response curves for recent earthquakes. Then we provide the recommended GMPE, as well as the justification for their choice. In short, here is presented only a small part of the material used by the experts for the final selection [10].

Methods. In this section, we present a general procedure developed for the selection of GMPE for three main tectonic regimes: SSR, ASR and MSR. Supervision of the project was carried out by the main group of experts and a wide group of experts, which included all members of the project group. The main group responded to the preparation of the initial GMPE recommendations for the three modes, which were then presented to a wide group of experts for discussion and possible review [11].

We defined the criteria for the selection of GMPE for the modes SSR and ASR as follows:

1. Much attention is paid to GMPE, obtained from international data sets. Exceptions may be made when the GMPE, received on the basis of a local data set, has been verified at the international level and recognized as effective.

2. Much attention is paid to GMPE, having the attributes of their functional form, which we consider desirable, such as the saturation of magnitude, the scaling of distances dependent on magnitude and conditions, do not affect.

If there are several GMPEs that are precisely limited to data, but demonstrate different trends, it is desirable to record these trends in selected GMPEs in order to properly represent epistemic indefiniteness [12].

For MSR, where the amount of data on ground motion was little, these criteria were modified as follows:

1. MSR GMPE is derived mainly from the results of numerical modeling. However, the way that restricted available data are used to limit input parameters for modeling is crucial. Empirical calibration can affect, for example, the parameters of stress drop and attenuation at the site. We prefer that GMPE effectively used the available data to limit the parameters of the model.

2. The same is the second criterion for the modes SSR and ASR (desirable signs of functional form). The range of data for MSR is limited so that the selected models are extrapolated to a reasonable range of data [13].

We are looking for GMPE, which meet the prerequisite criteria and in coincidence represent different geographical regions and use alternative modeling methodologies. This is intended to represent epistemic uncertainty in selected GMPEs [14].

In the process of choosing, we decided not to reduce the weight of GMPE due to difficulty of the parameters implementation, such as the condition of the depth of the pool or the depth to the top of the gap, so that these problems can be overcome with the help of a parameter [15]. We also did not reduce the weight of GMPEs where the site terms are missing, cause they can be estimated for a rock reference state in the hazard analysis and site effects are subsequently added in a hybrid process [16].

With the basic resources developed for the selection of GMPE, there was a synthesis of functional forms, graphs, showing a comparative scale of soil motion with predicted parameters (distance, magnitude, period etc.). Some models provide a simple linear scaling with a reduction of magnitude and distance, while others consider more complex effects [17]. These effects are discussed in comparative GMPE scaling charts.

Results. As an illustration of an example of the international GMPE models selection we chose a seismic hazard assessment work, carried out for the East Kazakhstan region.

As soon as the most part of the territory is belonged to the mode of active crustal regime, and the less part is in the stable region, two modes were highlighted within the process of soil shaking forecasting – active crustal seismic mode and stable mode. For this region, a comparative analysis and selection of GMPEs, developed for similar seismic soil conditions, was carried out. Active and stable seismic models were used to predict ground shakings in peak ground accelerations. Trellis plots of spectral accelerations attenuation with period at different distances from source were calculated, also spectral accelerations were studied and obtained results were compared.

For the active crustal mode, 5 models were used, including the Bommer-Akkar (2010), Zhao (2016), Abrahamson (2014), Boore (2014), Chiou-Young (2014) models, as soon as the weight of the Bommer-Akkar and Zhao models was 80%, weight the other models 20%. Three models were used for stable regions: NGAEast_Boore_AB14-J15, NGAEast_Darragh, NGAEast_Shahjouel-Pezeshk, whose weighs accounted for 30%, 40% and 30% respectively.

Figure 1 shows trellis plots for selected ground motion prediction models in active regions for spectral accelerations at different distances with period attenuation.

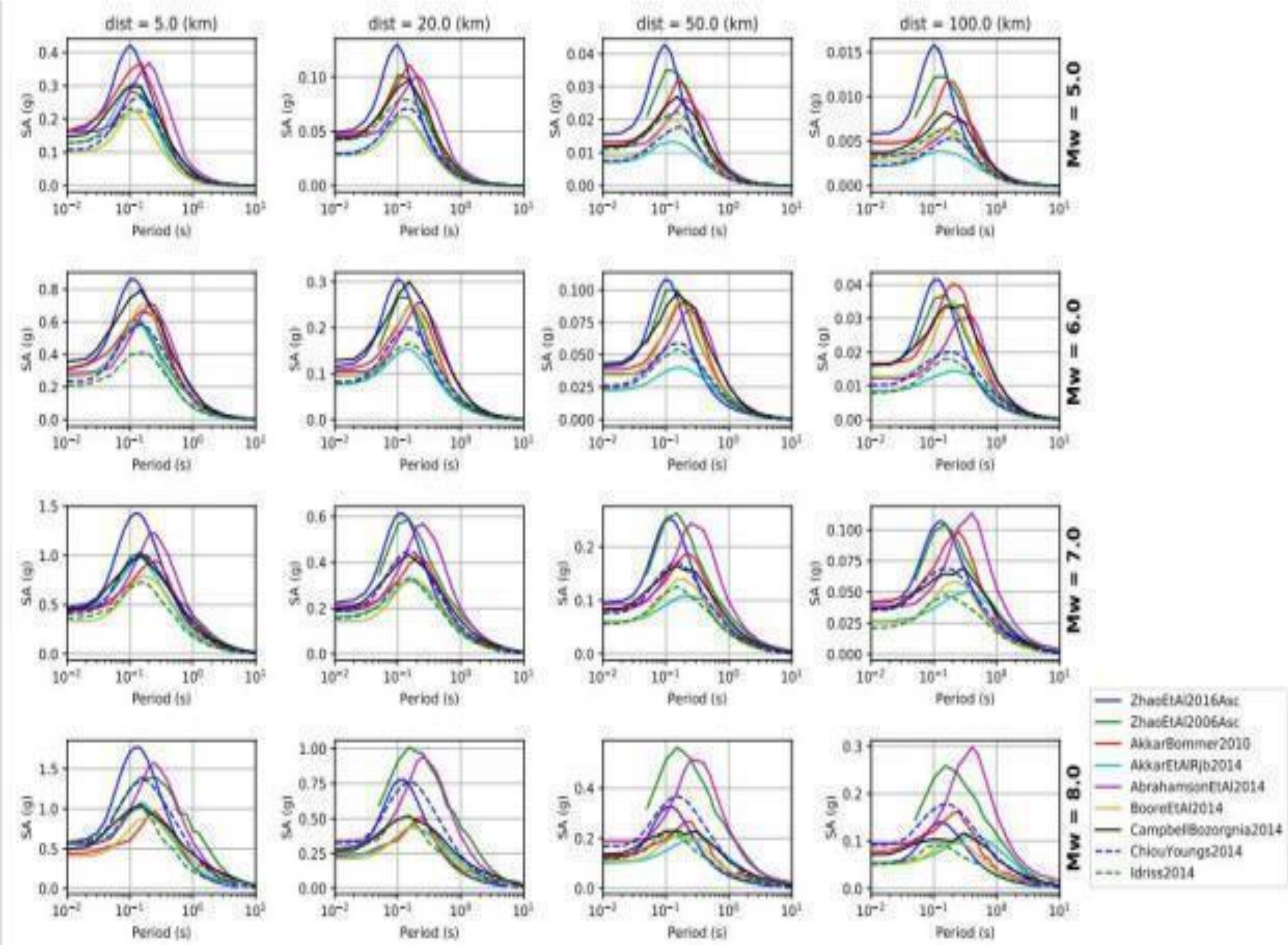

Fig. 1. Trellis plots of the considered ground motion prediction models
for earthquakes in tectonically active areas

Figure 2 shows examples of comparing the observed data with the models of Zhao et al. (2016) and Zhao et al (2006).

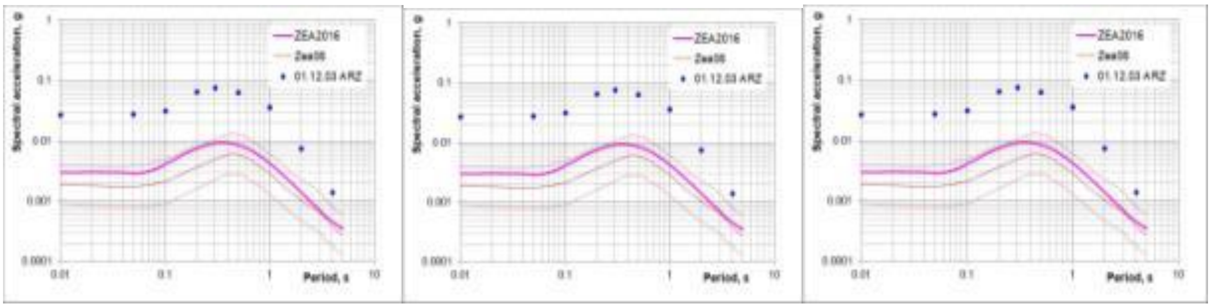

Fig. 2. Comparison of observed data with models by Zhao et al. (2016) and Zhao et al. (2006)

Discussion. In this article, we presented and used the method of selecting international ground motion models within the project OR11465449 – “Seismic hazard assessment of the territories, regions and cities of Kazakhstan on a modern scientific and methodological basis” provided by the Institute of Seismology from 2021 to 2023. GMPEs were obtained from NGA-East, NGA-West, and NGA databases. This procedure should be transparent, objective and reproducible in future projects, for example, for possible updates of the GMPEs. The procedure consists of expert reviews of several sources, including trellis plots, showing the scales of potential GMPEs dependences on the period, magnitude, distance, the functional forms of GMPE models, and the quantitative studies of model data comparisons.

The ground motion prediction equations, or attenuation ratios, express the individual soil shaking parameters in terms of the quantities on which they depend the most. The GMM pre-selection criteria are the reliability of the model, the ability to predict the entire range of magnitude-distance-periods of interest, the use of parameters used in modern international practice. The functional form should include the desired features, such as saturation with respect to magnitude, distance versus magnitude dependence, and terms that simulate inelastic damping effects. To adequately represent epithermal uncertainty, it is recommended to use models that show different trends if they are well supported by data. For each seismic and tectonic mode is applied an additional criteria for selecting predictive dependencies, related to the methods and features of their obtaining.

On the basis of expert analysis of the above-mentioned sources of information, a set of GMPE for each of the tectonic regimes was proposed, as described in the previous section. They consisted of five GMPEs for active crustal seismic mode, three GMPEs for stable mode. For active crustal regions the Bommer-Akkar (2010) and Zhao (2016) models were in better agreement with the data than Abrahamson (2014), Boore (2014), Chiou-Young (2014) models and had larger weights in calculation results.

We emphasize that the purpose of this article is to select a set of GMPE for hazard analysis, which could be used to obtain seismic hazard assessment maps, either on regional or local scale. In addition, the development of GMPE is constantly evolving in the field of research, and new or updated GMPE are regularly published, new available GMPEs become more empirical, and widely studied. Thus, the recommended GMPE set here should not be considered as a long-term recommendation, and it should be regularly reviewed.

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КҮШТІ ЖЕР ҚОЗҒАЛЫСЫ ҮШІН ӘЛСІРЕТУ МОДЕЛЬДЕРІН ТАҢДАУ ТУРАЛЫ

Аңдатпа. Күшті қозғалыстың әлсіреуі модельдері (GMPE) жер сілкінісі көрсеткіштерін жер сілкінісінің көзін, жолын және орнындағы әсерді сипаттайтын айнымалылармен байланыстырады. Көптеген қолжетімді GMPE-лердің ішінен біз сейсмикалық қауіпті бағалауда қолдануға жарамды және аймақтық сейсмотектоникалық жағдайларды ескеретін модельдерді таңдаймыз. Біз көпөлшемді жердегі қозғалыс тенденцияларын (мысалы, шама, қашықтық және құрылымдық кезеңде) бағалайтын, функционалдық пішіндерді зерттейтін және тәуелсіз деректерге қарсы GMPE өнімділігінің сандық сынақтарын бағалайтын GMPE таңдау процедурасын ұсынамыз. Біздің ұсыныстарымызға жер қыртысының сейсмикалық белсенді аймақтары үшін халықаралық модельдеуге негізделген модельдер, жер қыртысының тұрақты аймақтары үшін модельдер кіреді. Эпистемологиялық белгісіздіктерді болжау үшін іріктеу процесі қашықтық бойынша ыдырау жылдамдығы сияқты негізгі GMPE атрибуттарының балама көріністерін ескереді.

Негізгі сөздер: күшті жердегі қозғалыстардың әлсіреуі модельдері (GMPE), әлсіреуі, жердегі қозғалыстар.

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О ВЫБОРЕ МОДЕЛЕЙ ЗАТУХАНИЯ СИЛЬНЫХ ДВИЖЕНИЙ ГРУНТА

Резюме. Модели затухания сильных движений грунта (GMPE) связывают показатели сотрясений движений грунта с переменными, описывающими очаг землетрясения, путь и воздействие на месте. Из множества доступных GMPE мы выбираем те модели, которые подходят для использования при оценке сейсмической опасности и учитывают региональные сейсмотектонические условия. Мы представляем процедуру выбора GMPE, которая оценивает тенденции многомерного движения грунта (например, по величине, расстоянию и структурному периоду), исследует функциональные формы и оценивает количественные тесты производительности GMPE по сравнению с независимыми данными. Наши рекомендации включают международные модели, основанные на моделировании, для сейсмоактивных коровых регионов, модели для стабильных областей земной коры. Чтобы приблизительно учесть эпистемологические неопределенности, процесс выбора учитывает альтернативные представления ключевых атрибутов GMPE, таких как скорость затухания на расстоянии.

Ключевые слова: модели затухания сильных движений грунта (GMPE), затухание, движения грунта.