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MODELING OF STRONG GROUND MOTION PARAMETERS AND ARTIFICIAL INTELLIGENCE ALGORITHMS FOR DESCRIBING SEISMIC PROCESSES

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Summary. A systematic analysis of mathematical and geophysical principles applied to the modeling of strong ground motion parameters under seismic loading conditions has been performed. The focus of the study is on one of the key characteristics of the seismic process — the peak ground acceleration (PGA), which represents a fundamental indicator of earthquake intensity. The methodological framework of the research is based on the analysis of median ground motion models that formalise the dependence of seismic impact parameters on the source characteristics, hypocentral distance, and geophysical conditions of the medium. Models of aleatory uncertainty are examined, reflecting the natural variability of ground motion parameters and ensuring the statistical correctness of model parameterisation. Particular attention is given to stochastic modeling, which allows reproducing the probabilistic distribution of strong ground motion scenarios. The application of stochastic algorithms enables the inclusion of both typical and rare extreme events, which is crucial for seismic hazard assessment. The aim of the study is to develop recommendations for the selection and application of mathematically and geophysically justified models, artificial intelligence (AI) algorithms that meet the criteria of accuracy, reliability, and reproducibility. A comparative analysis of different approaches has revealed their respective strengths and limitations, as well as identified the optimal areas of practical application. The practical significance of the research lies in the fact that properly selected and geophysical validated models improve the accuracy of ground motion prediction and enhance the efficiency of engineering calculations during the design of buildings and structures.

1. Introduction

Azerbaijan is located within the central part of the Mediterranean mobile belt and is characterised by high geological activity associated with the interaction of the Arabian and Eurasian lithospheric plates. The region is characterised by high seismicity, modern manifestations of magmatism and mud volcanism, intense landslide processes, and contrasting vertical and horizontal crustal movements (Babayev G. et al., 2020). These processes are clearly manifested in various geostructural zones of the country: in the Azerbaijani part of the Greater and Lesser Caucasus, the Kur Depression, the Gusar-Shabran region, the South Caspian Basin, and the Talysh fold zone. Previous studies have demonstrated that strong earthquakes in the Caspian region can dynamically trigger mud volcano activity, highlighting the complex interaction between seismic waves and near-surface geological systems (Babayev G. et al., 2019).

In recent decades, particularly between 2000 and 2025, seismic and tectonic activity has increased in the country and adjacent regions. Both earthquake sources within Azerbaijan and sources in neighboring countries have intensified, influencing the country's seismic hazard (Babayev T. et al., 2025a). Particular attention is being paid to the northern part of the country –the Greater Caucasus Thrust Zone – where regular observations are conducted using modern seismological equipment.

Under these conditions, developing and improving regional models for predicting strong ground motion parameters is crucial for seismic hazard assessment and the adaptation of building codes. Azerbaijan's modernised seismic system currently allows the calculation of peak ground acceleration (PGA), peak ground velocity (PGV), and peak ground displacement (PGD), taking into account regional characteristics. The development and updating of such models will improve the accuracy of calculations used in engineering seismology and the development of detailed seismic zoning maps.

This study presents a comprehensive analysis of mathematical and geophysical approaches used in modeling strong ground motion parameters, including median prediction models, aleatory variability assessment, and stochastic modeling methods. From a geophysical perspective, the interpretation of the obtained relationships is based on taking into account the physical properties of earthquake foci, the structure of the lithosphere, and the propagation characteristics of seismic waves in various tectonic and geostructural zones. Given the multifactorial nature of the models under consideration (Bayramov et al., 2024), the results of the analysis provide a solid foundation for the development of physically based and regionally adapted ground motion models. The findings can contribute to improved seismic hazard assessment and the selection of reliable, geophysically correct models applicable to the specific seismotectonic conditions of Azerbaijan.

2. Ground motion models

The paper (Chernov et al., 2019) examines the development of effective models for strong ground motions during potentially hazardous earthquakes in the Alania region (Vladikavkaz, Russia). Models of individual ground motion characteristics are considered: peak ground accelerations PGA, periods of acceleration with maximum amplitude *Ta*, durations of the main phase of oscillations (τ), and macroseismic intensity of shaking (*I*). The earthquake intensity I at a given point is approximately proportional to the logarithm of the peak acceleration (1):

$$log_2 A_{max} \approx 0{,}1 \cdot 2(I-7) \qquad (1)$$

here A_{max} is the peak acceleration in fractions of the acceleration of gravity *g*, *I* is the intensity of the earthquake at a given point.

The models are presented as probability distribution functions for the values of ground shaking parameters and magnitudes for various earthquake magnitudes (*M*) and distances to the source (*D*). First, the average statistical functions *PGA* (*M*, *D*), *Ta* (*M*, *D*), τ (*M*, *D*), and *I* (*M*, *D*) are determined. Then these functions are approximated to the conditions of the study area introducing corrections into these dependencies. The corrections are determined based on an analysis of the general seismotectonic conditions of the area, the characteristics of the seismic disturbance propagation environment, focal mechanisms, and other characteristics of the study region (Fig. 1). The authors of the article claim that the data they obtained contribute to increasing the accuracy and reliability of probabilistic assessments of seismic hazard and can be used for detailed seismic zoning.

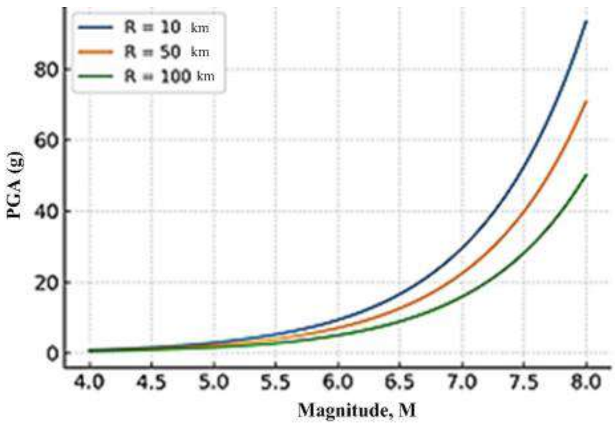

Fig. 1. Illustration of the relationship between PGA and magnitude for different source-to-site distances

In the works (Babayev G. et al., 2010; Babayev G. and Telesca, 2014), using macroseismic data from November 25, 2000 earthquake, an integrated analysis of seismicity, engineering geology, geomorphology, topography, and the impact of soil conditions was carried out in order to model one of the parameters of strong movements, maximum ground acceleration, and an assessment of the distribution dynamics over the area of the Absheron peninsula and the city of Baku. The authors found that most of the peninsula corresponds to an intensity of VIII–IX.

Figure 2 is a bar chart showing the importance of factors in predicting ground motion parameters.

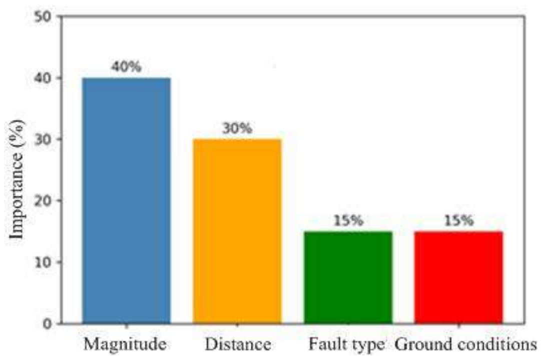

Fig. 2. Chart illustrating the contribution of different parameters to PGA prediction

The diagram shows that earthquake magnitude has the greatest influence on ground motion parameters, followed by distance to the epicenter. The contribution of fault type and soil conditions is significantly smaller, but they are also necessary for accurate forecasts.

3. Local geological conditions in modeling of strong ground motion parameters

Accounting for local geological conditions largely determine the nature and intensity of seismic effects at the surface. Even with identical earthquake source parameters (magnitude, depth, epicentral distance), significant variations in peak ground acceleration (PGA) values are observed due to differences in the engineering-geological properties of the medium. The key parameters influencing soil behavior under dynamic loading include density, elastic modulus, Poisson's ratio, as well as the velocities of compressional (Vp) and shear (Vs) waves. The shear wave velocity (Vs) is considered the most informative indicator and is widely used for classifying soils according to their seismic properties. Soils with low Vs values (loose, water-saturated deposits) tend to amplify seismic waves, whereas rock and dense soils are characterised by lower response amplitudes. In the initial problem formulation, the influence of local conditions was taken into account through the categorical parameter "soil type," used as one of the inputs to the neural network. However, to improve the accuracy and physical validity of the model, it is proposed to extend this approach by incorporating quantitative engineering-geological characteristics. In particular, the use of parameters such as Vs30, thickness of unconsolidated deposits, as well as damping and nonlinear soil behavior indicators is considered.

In addition to soil and lithological properties, specific geological features such as mud volcano systems may also respond dynamically to seismic excitation. Studies indicate that seismic waves can trigger mud volcanic activity in Azerbaijan, emphasizing the importance of accounting for such coupled geological processes in seismic hazard assessment (Babayev G. et al., 2019).

A significant role is played by the effect of local amplification associated with contrasts in the elastic properties of layers, as well as resonance phenomena that occur when the natural frequencies of the soil column coincide with the dominant frequencies of the seismic signal. Under such conditions, a substantial increase in motion amplitudes may be observed, directly affecting PGA values. Accounting for these effects is especially important while assessing seismic hazard in areas with complex geological structures. From the perspective of artificial intelligence algorithms, the incorporation of local conditions is achieved by expanding the input parameter vector and training the model on a more representative dataset reflecting the diversity of geological environments. The integration of additional parameters enables the neural network to capture more complex nonlinear relationships between medium characteristics and seismic response parameters. In the future, hybrid approaches combining machine learning methods with numerical modeling of seismic wave propagation may also be employed.

Thus, detailed consideration of local geological conditions is a necessary prerequisite for improving the accuracy of modeling strong ground motion parameters. Expanding the set of input parameters and conducting a deeper analysis of engineering-geological characteristics significantly enhances the predictive capability of the proposed model and ensures a more reliable assessment of seismic effects.

4. Median ground motion model

The study by Campbell and Bozognia (2008) introduced an empirical model describing median ground motion, enabling the estimation of PGA, PGV, PGD, as well as 5% damped linear elastic response spectra over a period range of 0.01 to 10 seconds. The model was developed using data from the PEER NGA database, which includes records of mainshock earthquakes occurring in active tectonic regions. Records deemed inappropriate for evaluating shallow ground motion were excluded from the dataset (Ancheta et al., 2013). The authors established relationships for the standard deviation of the horizontal geometric mean of ground motion. These relationships were applied to earthquakes with magnitudes between 4.0 and approximately 7.5–8.5 (depending on the faulting mechanism) and for source-to-site distances ranging from 0 to 200 km. The model incorporates several influencing factors, including magnitude saturation effects, attenuation with distance, faulting style, rupture depth, hanging-wall effects, both linear and non-linear site conditions, three-dimensional soil behavior, and both inter-event and intra-event variability.

To estimate the median ground motion, the authors proposed equation (2)

$$Ln\hat{Y} = f_{mag} + f_{dis} + f_{flt} + f_{hng} + f_{site} + f_{sed} \quad (2)$$

Here: Y is the median estimate of the geometric mean of the horizontal component, f_{mag} is the magnitude function, f_{dis} is the distance function, f_{flt} is the function describing the fault mechanism, f_{hng} is the function describing the hanging block (layer) of the fault, f_{site} is the response function of the soil section, f_{sed} is the response function of the synclinal fold (recall that this is a type of folded bending of the layers of the Earth's crust characterised by a concave shape, an inclination of the layers to the axis and the occurrence of younger layers in the axial part and older ones on the wings.

5. Aleatory uncertainty model

Soil non-linearity (inhomogeneity) causes the standard deviation within an event to depend on the PGA amplitude of the supporting rock rather than on the magnitude, resulting in reduced aleatory uncertainty at high ground shaking levels (Liou and Abrahamson, 2025). Recall that aleatory uncertainty, or statistical uncertainty, is associated with the inherent randomness and variability of a system or process and arises from the stochastic nature of the environment, material inhomogeneity, temporal fluctuations, and spatial variations.

According to the random effects' regression analysis used to obtain the median ground motion model, the aleatory uncertainty model is given by equation (3):

$$LnY_{ij} = Ln\hat{Y}_{ij} + \eta_i + \varepsilon_{ij} \qquad (3)$$

Here: η_i is the parameter characterizing the between-event residual for event i; $\hat{Y}_{ij}$, Y_{ij}, and ε_{ij} are the predicted value, observed value, and within-event residual, respectively, for record j of event i. Independent normally distributed variables η_i and ε_{ij} have zero means and estimated between-event and within-event standard deviations τ and σ, given by equations (4), (5), (6)

$$\tau = \tau_{lnY} \qquad (4)$$

$$\sigma = \sqrt{\sigma^2_{lnY_B} + \sigma^2_{lnAF} + \alpha^2\sigma^2_{lnA_B} + 2\alpha\rho\sigma_{lnY_B}\sigma_{lnA_B}} \qquad (5)$$

where the overall standard deviation equals

$$\sigma_T = \sqrt{\sigma^2 + \tau^2} \qquad (6)$$

The authors believe that the proposed model is suitable for estimating PGA, PGV, PGD, and for the linear-elastic response spectra T = (0.01–10) s for weak continental earthquakes occurring in western North America and in other regimes of similar active tectonics (Campbell, Bozorgnia 2006; Stafford et al., 2008). The model is considered the most reliable for evaluation for 4.0 < M < 8.5 for ground slip, M < 8.0 for back thrusts, and M < 7.5 for normal faults; for tremor depths of 0–200 km; and seismic wave velocities of 150–1500 m/s.

6. Stochastic modeling

The work (Pavlenko V. and Pavlenko O., 2023) carried out studies of the parameters of vibrations of the Earth's surface during possible strong earthquakes in the future: peak accelerations and velocities, intensity, response spectra, duration, prevailing periods of vibrations and others in the Baikal rift zone. These parameters need to be assessed for the specific conditions of construction sites. The equation for predicting peak accelerations and velocities on rocky soil, depending on the magnitude of the earthquake and the distance from the source (Pavlenko V., Pavlenko O., 2023) based on records of local earthquakes, can be used in problems of assessing seismic hazard in the Baikal rift zone.

In the matter of choosing the functional form of the ground motion prediction equation (GMPE), the author adopted the equation (Boore and Atkinson, 2008), which made it possible to obtain the desired effects. The equation looks like (7):

$$ln(Y) = F_M(M) + F_D(R, M) + \varepsilon\sigma \qquad (7)$$

Here: Y is a value of peak ground acceleration (PGA) in fractions of g or peak ground velocity (PGV) in cm/s; functions F_M and F_D describe the functional dependence on magnitude and distance, i.e. focal and pathway effects; M is an earthquake magnitude; R is an epicentral distance, or Joyner-Boer distance (the shortest distance from the observation point to the projection of the rupture plane onto the Earth's surface); ε is a residual of the regression model, reflecting the spread of observed values relative to the estimates of the regression model; σ is a standard deviation of the residual distribution.

To determine the values of the parameters of equation (6), the author used a two-stage regression method (Boore and Atkinson, 2008), which allows separating the determination of coefficients in the F_D and F_M functions. The resulting prediction equation for ground motion is applicable for $M = 4 \div 8$ and $R = 1 \div 200$ km. At the same time, observational data show a noticeable anisotropy of the medium, i.e. differences, at least, in the attenuation characteristics of seismic waves in different directions.

The work (Khalid and Razbin, 2024) presented a ground motion prediction model (GMPM) using Artificial Intelligence (AI) technology (Suleymanov et al., 2025), in particular, an artificial neural network (ANN) for shallow earthquakes, aimed at improving earthquake safety assessment. The proposed model uses the main input variables such as magnitude, fault type, epicentral distance and soil type, and the output variable is peak ground acceleration (PGA) at 5% attenuation.

To develop this model, 885 pairs of data were obtained from the Pacific Engineering Research Center, providing a robust data set for machine learning and algorithm testing. The ANN architecture includes 4 neural network nodes in the input layer, two hidden layers each containing 25 neural network nodes, and an output layer with one node, resulting in 750 unknown weights and biases that the model must optimise (Dhanya et.al., 2019). After evaluating the model, the genetic algorithm was integrated with the artificial neural network model to improve its predictive capabilities. This integration aims to predict 20 potential earthquake scenarios, an important step in validating the model's performance. Figure 3 illustrates a flowchart derived from an analysis of this methodology (Dhanya et.al., 2019).

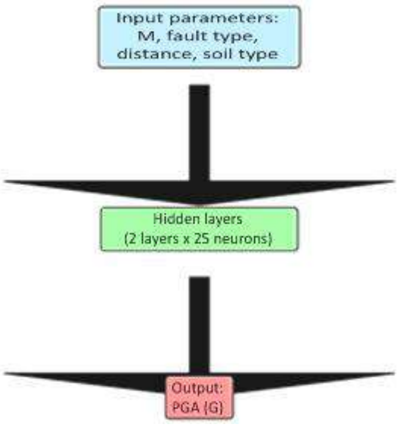

Fig. 3. Schematic structure of the artificial neural network for PGA prediction

The results (Dhanya et.al., 2019) were promising as the proposed model successfully predicted earthquakes in 15 out of 20 scenarios. These results highlight the high potential of the model in accurately predicting seismic events.

The summary analysis by the authors in the current study showed that ANN provided more accurate predictions. This highlights the need to update forecast models on the region (Babayev T. et.al., 2025b).

Analysis of the dependence of PGA on the hypocentral distance for various magnitudes (Fig. 4) shows a regular attenuation of seismic vibrations with increasing distance to the source. At the same time, earthquakes of greater magnitude are characterised by significantly higher PGA values and a longer radius of influence. This result confirms that magnitude and distance to the source are key factors determining the intensity of ground motion. The construction of this graph made it possible not only to visualise the physical nature of the attenuation, but also to justify the choice of these parameters as input nodes of the artificial neural network.

The graph plotted in this study serves as a starting point for developing and training an ANN model: it shows the range of values within which the neural network should capture patterns.

7. Conclusion

During the study, a comprehensive analysis of existing mathematical and geophysical models for predicting the parameters of strong ground motions was performed, taking into account median characterristics, aleatory uncertainty and stochastic modeling approaches. The geophysical aspect of the analysis is based on taking into account the seismotectonic conditions of the region, the structure of the lithosphere, the heterogeneity of velocity sections of the Earth's crust and local features of soil massifs that affect the amplitude-frequency parameters of vibrations. The models considered make it possible to assess seismic hazard in various tectonic zones and geological environments, however, each of them has its own limitations associated with the initial data, the range of applicability in magnitude and distance, as well as the type of soil foundation. The main input parameters are magnitude, fault type, epicentral distance, and soil type, while the output parameter is peak ground acceleration (PGA) at 5% damping. The structure of the neural network used consists of 4 nodes in the input layer, two hidden layers each containing 25 nodes, and an output layer with a single node, resulting in 750 unknown weights and biases that the model must optimise. After model evaluation, a genetic algorithm was integrated with the artificial neural network to improve its predictive capabilities. A total of 20 potential earthquake scenarios were predicted, which is an important step in validating the model's effectiveness. The proposed model successfully predicted earthquakes in 15 out of 20 scenarios, corresponding to a prediction accuracy of 75%. These results highlight the high potential of the model for accurate forecasting of seismic events in Azerbaijan.

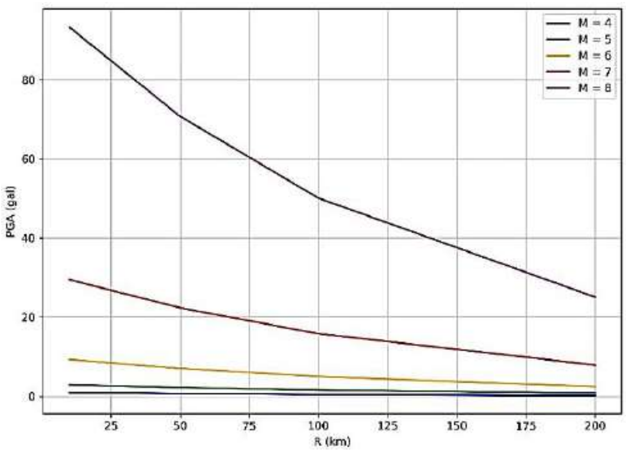

Fig. 4. Graph of the dependence of the hypocentral distance (R) on the PGA for different magnitudes (M)

Particular attention is paid to the integration of modern artificial intelligence technologies, in particular, artificial neural networks, which demonstrate high predictive ability and allow considering complex non-linear relationships between earthquake parameters and ground motion characteristics. A geophysical based combination of traditional physical models and machine learning algorithms opens up the possibility of creating a new generation of hybrid models, where physical and mathematical equations describe seismic processes, and neural network methods clarify non-linear dependencies and regional effects.

Prospects for further research include next:

- development of regionally adapted equations for predicting ground movements for the territory of Azerbaijan, taking into account its seismotectonic structure and fault systems;
- expansion of the database through local and international seismological records and the inclusion of geophysical observation data;
- integration of GIS technologies for spatial modeling of zones of potential strong shaking using seismic geological parameters;
- application of hybrid models (physical + AI) to improve the accuracy of forecasts and ensure physical interpretability of results.

The implementation of these areas will improve the reliability of seismic hazard mapping, optimise the design of earthquake-resistant structures and reduce potential risks for the population and infrastructure.

REFERENCES

Ancheta TD et al (2013) PEER NGA-West2 Database, PEER Report 2013-03. Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA

Babayev G, Ismail-Zadeh A, Le Mouel J –L (2010) Scenario-based earthquake hazard and risk assessment for Baku (Azerbaijan). Nat. Hazards Earth Systems Science 10(12):2697–2712. https://doi.org/10.5194/nhess-10-2697-2010

Babayev G and Telesca L (2014) Strong motion scenario of 25th November 2000 earthquake for Absheron peninsula (Azerbaijan). Journal of Natural Hazards 73:1647–1661, Springer Natural Link. https://doi.org/10.1007/s11069-014-1159-7

Babayev G, Kadirov F, Tibaldi A, Bonali F, Aliyev Y (2019) Dynamic triggering of mud volcanos in Azerbaijan by Caspian earthquakes. ANAS Transactions, Earth Sciences 2:47–53. https://doi.org/10.33677/ggianas20190200031

Babayev G, Telesca L, Agayeva S, Ismail-zade T, Muradi I, Aliyev Y, Aliyev M. (2020) Seismic hazard analysis for southern slope of the Greater Caucasus (Azerbaijan). Pure and Applied Geophysics 177(8):3747–3760. Springer Natural Link. https://doi.org/10.1007/s00024-020-02478-0

Babayev T, Babayev G, Irawan S, Bayramov E (2025b) Development of ANN-based data-driven ground motion model for Azerbaijan using temporal earthquake records of 2022–2024. Front Earth Si 13:1571640. https://doi.org/10.3389/feart.2025.1571640

Babayev TH and Aliyev YN, Babayev GR (2025a) Clustering analysis of 100-year international seismic catalogue for Azerbaijan. Geology and Geophysics of Russian South 15(1):105–118. https://doi.org/10.46698/VNC.2025.99.31.009

Bayramov AA, Abdullayev FN, Suleymanov SS, Karimova RD, Safarov HN, Rzayev EA (2024) Multifactor model for seismological research. Seismoprognosis observations in the territory of Azerbaijan 26(2):28–33. https://doi.org/10.59849/2219-6641.2024.2.28

Boore DM and Atkinson GM (2008) Ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5%-damped PSA at spectral periods between 0.01 s and 10.0 s. Earthquake Spectra 24(1):99–138. https://doi.org/10.1193/1.2830434

Campbell KW and Bozorgnia Y (2006) Next generation attenuation (NGA) empirical ground motion models: can they be used in Europe? Proceedings of the First European Conference on Earthquake Engineering and Seismology 458:01–10. Geneva, Switzerland

Campbell KW and Bozorgnia YN (2008) NGA Ground motion model for the geometric mean horizontal component of PGA, PGV, PGD and 5% damped linear elastic response spectra for periods ranging from 0.01 to 10 s. Earthquake Spectra 24(1):139–171. https://doi.org/ 10.1193/1.2857546

Chernov YuK, Chernov AYu, Chitishvili MI (2019) Models of strong ground motions for probabilistic detailed seismic zoning of the territory of North Ossetia-Alania. Part I. Geology and Geophysics of the South of Russia 9(2):95–108. https://doi.org/10.23671/VNC.2019.2.31980

Dhanya, J, Sagar D, Raghukanth STG (2019) Predictive models for ground motion parameters using artificial neural network. In: Rao A, Ramanjaneyulu K (eds) Recent Advances in Structural Engineering, vol. 2. Series: Lecture notes in civil engineering, vol 12. Springer, Singapore. https://doi.org/10.1007/978-981-13-0365-4_8

Khalid F and Razbin M (2024) Modeling peak ground acceleration for earthquake hazard safety evaluation. Scientific Reports 14(31032). https://doi.org/10.1038/s41598-024-82171-7

Liou IY and Abrahamson N (2025) Framework for aleatory variability and epistemic uncertainty for the Ground-Motion characterization based on the level of simplification. Bulletin of the Seismological Society of America 115(1):296–314. https://doi.org/10.1785/ 0120240141

Pavlenko VA and Pavlenko OV (2023) Stochastic modeling and development of an equation for predicting ground movements in the Baikal rift zone. Physics of the Earth 1:54–66. https://doi.org/10.31857/S0002333723010039 (in Russian)

Stafford PJ, Strasser FO, Bommer JJ (2008) An evaluation of the applicability of the NGA models to ground-motion prediction in the Euro-Mediterranean region. Bull. Earthquake Eng. 6(2):149–177.

Suleymanov S, Bayramov AA, Abdullayev FN (2025) Studing of seismic processes using AI technology. Current directions of development of information and communication technologies and control tools. Proceedings of 15-th International Scientific and Technical Conference 1(1):47, April 24–25 2025, Kharkiv. https://doi.org/10.32620/ICT.25.tl

МОДЕЛИРОВАНИЕ ПАРАМЕТРОВ СИЛЬНЫХ КОЛЕБАНИЙ ГРУНТА И АЛГОРИТМЫ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА ДЛЯ ОПИСАНИЯ СЕЙСМИЧЕСКИХ ПРОЦЕССОВ

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Резюме. Выполнен системный анализ математических и геофизических принципов, применяемых при моделировании параметров сильных движений грунта в условиях сейсмических воздействий. В центре внимания находится одна из ключевых характеристик сейсмического процесса — максимальное ускорение грунта, являющееся важнейшим индикатором интенсивности землетрясений. Методологическая основа исследования опирается на анализ медианных моделей движения грунта, позволяющих формализовать зависимость параметров сейсмического воздействия от исходных характеристик очага, гипоцентрального расстояния и геофизических условий среды. Рассматриваются модели алеаторной неопределённости, отражающие природную изменчивость параметров движения, что обеспечивает корректность параметризации и возможность учёта статистического разброса данных наблюдений. Особое внимание уделено стохастическому моделированию, позволяющему воспроизводить вероятностное распределение сценариев сильных движений. Применение стохастических алгоритмов обеспечивает охват как типовых, так и редких экстремальных событий, что имеет принципиальное значение для оценки сейсмической опасности. Цель исследования — разработка рекомендаций по выбору и применению математических и геофизически обоснованных моделей, алгоритмов ИИ, удовлетворяющих критериям достоверности, надёжности и воспроизводимости результатов. Сравнительный анализ различных подходов позволил выявить их сильные и слабые стороны, а также определить оптимальные области практического использования. Практическая значимость заключается в том, что корректно выбранные и геофизически обоснованные модели обеспечивают повышение точности прогнозирования параметров сейсмических воздействий и оптимизацию инженерных расчётов при проектировании зданий и сооружений.

Ключевые слова: *землетрясение, сильные движения грунта, максимальное ускорение грунта, математическое моделирование, срединные модели, стохастическое моделирование, искусственный интеллект*

SEYSMİK PROSESLƏRİN TƏSVİRİ ÜÇÜN GÜCLÜ YER HƏRƏKƏTİ PARAMETRLƏRİNİN MODELLƏŞDİRİLMƏSİ VƏ SÜNİ İNTELLEKT ALQORİTMLƏRİ

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Xülasə. Seysmik təsirlər altında güclü yer hərəkətlərinin parametrlərinin modelləşdirilməsində istifadə olunan riyazi və geofiziki prinsiplərin sistemli təhlili aparılmışdır. Diqqət seysmik prosesin əsas xüsusiyyətlərindən biri üzərindədir: zəlzələ intensivliyinin ən mühüm göstəricisi olan maksimum yer sürətlənməsi. Tədqiqatın metodoloji əsası seysmik təsir parametrlərinin mənbənin ilkin xüsusiyyətlərindən, hiposentral məsafədən və ətraf mühitin geofiziki şərtlərindən asılılığını rəsmiləşdirməyə imkan verən yer hərəkətinin median modellərinin təhlilinə əsaslanır. Tədqiqatın geofiziki konteksti litosferin strukturunu, yer qabığının sürət bölmələrinin heterojenliyini, seysmik dalğaların yayılmasının xüsusiyyətlərini və yerli geoloji şəraitin rəqslərin amplituda-tezlik xüsusiyyətlərinə təsirini əhatə edir. Bu amillər proqnoz tənliklərinin formasını və yer hərəkətinin təhlilində istifadə olunan modellərin parametrlərini müəyyən edir. Hərəkət parametrlərinin təbii dəyişkənliyini əks etdirən aleator qeyri-müəyyənlik modelləri nəzərdən keçirilir ki, bu da parametrləşdirmənin düzgünlüyünü və müşahidə məlumatlarının statistik səpələnməsini nəzərə almaq imkanını təmin edir. Güclü hərəkət ssenarilərinin ehtimal paylanmasının təkrar istehsalına imkan verən stoxastik modelləşdirməyə xüsusi diqqət yetirilir. Stokastik alqoritmlərin istifadəsi həm tipik, həm də nadir ekstremal hadisələrin əhatə olunmasını təmin edir ki, bu da seysmik təhlükənin qiymətləndirilməsi üçün əsasdır. Tədqiqatın məqsədi nəticələrin etibarlılıq, etibarlılıq və təkrar istehsal meyarlarına cavab verən riyazi və geofiziki cəhətdən təsdiqlənmiş modellərin və süni intellekt alqoritmlərinin seçilməsi və tətbiqi üçün tövsiyələr hazırlamaq idi. Müxtəlif yanaşmaların müqayisəli təhlili bizə onların güclü və zəif tərəflərini müəyyən etməyə, həmçinin praktiki tətbiq üçün optimal sahələri müəyyən etməyə imkan verdi. Praktiki əhəmiyyəti ondan ibarətdir ki, düzgün seçilmiş və geofiziki cəhətdən əsaslandırılmış modellər seysmik təsir parametrlərinin proqnozlaşdırılmasında artan dəqiqliyi və bina və tikililərin layihələndirilməsində mühəndis hesablamalarının optimallaşdırılmasını təmin edir.

Açar sözlər: *zəlzələ, güclü yer hərəkəti, maksimum yer sürəti, riyazi modelləşdirmə, orta modellər, stokastik modelləşdirmə, süni intellekt*