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MAGNETO-BASED EARTHQUAKE HAZARD MODELS FOR ABSHERON PENINSULA

Babayev G.R.[1,2], Aliyev Z.V.[1]
[1]Ministry of Science and Education of the Republic of Azerbaijan,
Institute of Geology and Geophysics, Azerbaijan
119, H.Javid ave., Baku, AZ1143
[2]Azerbaijan State Oil and Industry University, Azerbaijan
20, Azadlig Ave., Baku, AZ1010

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Summary. An earthquake hazard model based on the variations of magnetic susceptibility of rocks integrating with macroseismic parameters of a credible earthquake, considering dynamics of the site effects was developed and applied to the Absheron peninsula (Azerbaijan). Magnetic well logging data, lithological and geological maps of the Absheron peninsula, seismic catalogues were also utilized. The maximum expected ground motion for Absheron is estimated for shallow Baku-Caspian 25.11.2000 earthquake near the site, which is noted as a scenario "near-event earthquake" and considered as credible earthquake with moment magnitudes Mw=6.18 and Mw=6.08. The moment magnitude is accepted as Mw=6.8. Local site effect assessment was carried out by detailed geotechnical investigation of soil from bedrock to surface using one-dimensional (1-D) ground response analysis with SHAKE2000. We estimated the response of soil layers under earthquake effect by computing soil amplification and the variation of ground motion characteristics on the surface. Based on the scenario earthquake parameters, the surface peak ground acceleration is computed, correlated with the MSK-64 intensity, and mapped. We simulated ground acceleration, seismic intensity and magnetic susceptibility. The northeast and southeast parts of the peninsula are characterized by surface peak ground acceleration of 165-250 gal and intensity VIII-IX, which is 31% and 49% higher than the seismic hazard in the same values compared to other parts. For the eastern part, magnetic susceptibility varies between 0.5-1.0. The values indicate the distinct relationship of variations in the magnetic field with the seismic effect of earthquakes. Our approach makes a significant contribution to improving existing methods for seismic hazard assessment.

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Introduction

Magnetic properties of rocks in the fault zones are natural archives of the fault associated processes in tectonically active regions. It generates rock magnetism, which is the study of the magnetic properties of rocks, sediments, soils, and even fossils, a promising tool to unravel faulting processes (Yang et al., 2020). The rock's magnetic features are sensitive to both chemical and physical changes occurring in rocks during the faulting. For example, variations in physical grain size are often reflected in magnetic granulometry, which is the (inferred) grain-size distribution of magnetic particles in a sample, usually expressed through the magnetic domain structure (Yang et al., 2020).

The magnetic properties of fault rocks can be used as tracers for physical and chemical alterations caused by frictional heating during earthquakes (Pei et al., 2014). Magnetic susceptibility and rock magnetism have commonly been used to understand fault slip zones' physical characteristics and chemical processes (Enomoto and Zheng, 1998; Nakamura and Nagahama, 2001; Ferré et al., 2005, 2012).

Recently, a few studies (Wenchuan Earthquake with Mw=7.9, 2008) of high magnetic susceptibility within fault gouges have been described from several faults related to large earthquakes (Enomoto and Zheng, 1998; Nakamura and Nagahama, 2001; Fukuchi et al., 2005; Hirono et al., 2006; Mishima et al., 2006, 2009). It permits the utilization of magnetic properties of rocks in terms of magnetic susceptibility to integrate with seismic effect parameters of credible earthquakes to assess seismic hazard for the area of the study.

In this paper we model earthquake hazard assessment with consideration of the rocks' magnetic susceptibility variations integrating with a credible earthquake's macroseismic parameters (magnitude, depth, location, epicentral distance) and site effects applied to the Absheron peninsula in Azerbaijan.

The Absheron peninsula is situated in the central part of the Alpine-Himalayan seismic belt and is involved in the dynamics of lithospheric structural units of the Arabian and Eurasian plates (Jackson et al., 2002). This lithosphere dynamics results in stress-strain localization and release in earthquakes, magmatic and mud volcanism, landslides, and other active geological and geophysical processes (Panahi, 2003). Absheron peninsula, together with the part of the adjacent basin of the Caspian Sea (Azerbaijan), is located on the south-eastern border of the Greater Caucasus.

Earthquakes in the region migrate along the Alpine-Himalayan seismic belt (Ismail-Zadeh et al., 1996) and are associated with the fault zones located either in the peninsula itself, in the Azerbaijan sector of the Caspian Sea, or in the adjacent folding structures of the Greater Caucasus and Kopet-Dag (Jackson et al., 2002).

Seismically, there are two main active zones affecting the Absheron peninsula. The northern zone is a part of the North Caucasus thrust belt that continues to the east along the Absheron Sill, which is interpreted to be a zone of active subduction (Jackson et al., 2002). Earthquakes occurring in the northern zone are mainly deep reverse or shallow normal focal mechanisms (Jackson et al., 2002). The southern zone is interpreted to be a continuation of the Greater Caucasus thrust. Earthquakes in this area are mainly reverse or right-lateral strike-slip focal mechanisms (Babayev et al., 2010). The peninsula was shaken because of earthquakes from adjacent focal zones (Shamakhi-Ismayilli and the Caspian Sea), including several large and destructive events (Babayev et al., 2010). More recently, in 2000, two consequent earthquakes with moment magnitudes Mw=6.18 and Mw=6.08 struck the peninsula with some human losses and slight damages to buildings, felt by citizens of an area with a large radius (Babayev et al., 2020). The mentioned earthquake occurred in the southern zone of the Absheron peninsula.

Geologically, the Absheron peninsula is represented by a Quaternary system (Holocene and Pleistocene period) in the northeastern and southeastern parts of the peninsula, a Neocene and Quaternary system (Upper Pliocene and Pleistocene period) in the middle part of the peninsula, and a Neogene (Upper Miocene and Lower Pliocene period) in the southwestern part of the peninsula (Alizadeh, 2008).

Lithologically, the study area is composed mainly of clay, sand, sandstone, and limestone of solid and semi-solid configuration. Clay and sand layers are observed more than solid and semi-solid rocks, such as limestone and sandstone, in the different parts of the peninsula (Table 1). Consideration of the lithological factor is one of the important steps in seismic hazard assessment research and is an essential parameter in seismic hazard analysis (Babayev et al., 2010; Babayev and Telesca, 2016; Murphy and O'brien, 1977; Panza et al., 2011).

In this study, the maximum expected ground motion for the Absheron peninsula is estimated based on the shallow Baku-Caspian earthquake that occurred on November 25, 2000, with moment magnitudes Mw=6.18 and Mw=6.08, which is accepted as scenario "near-event earthquake" and considered as a credible one. Consequently, the relationship between seismic effect parameters and magnetic susceptibility values was analyzed to advance earthquake hazard assessment with application for the Absheron peninsula.

In this study, we applied the macroseismic parameters (magnitude, depth, hypocentral and epicentral distance) of the near-event earthquake and researched the magnetic susceptibility of grounds and soils. Our main objective was to identify a potential relation between the seismic effect and the magnetic properties of rocks in terms of peak ground acceleration (PGA), intensity of shaking, and magnetic susceptibility distributions.

Methodological approach

Choosing the right method (or number of methods) can be based on a qualitative-quantitative estimate. For this purpose, reliable informational and statistical criteria are needed to apply firstly these criteria to geology and geophysics (Eppelbaum, 2014).

For this current research, first and foremost, it was necessary to select scenario earthquakes in order to conduct a correlation between seismic effect parameters of earthquakes and the magnetic susceptibility of rocks. Thus, the 25.11.2000 Baku-Caspian "near-event earthquake" was employed as a scenario earthquake. Magnitude, location of the earthquake epicenter to the investigated site, location on the fault zones, effects on the area, and depth of earthquake (h=35 km) are important criteria in choosing this seismic event as a scenario. Macroseismic parameters (magnitude, depth, hypocentral and epicentral distance) of the scenario earthquake were taken from local and international catalogues. Based on the method of seismic hazard assessment (Babayev et al., 2024), it was considered effective to take the magnitude of the near-event earthquake for this study at 6.8. Thus, the seismic effect from the near-event earthquake parameters with hypothetic moment magnitude Mw=6.8 and 35 km focal depth (h) was assessed.

We integrated analysis of geology in terms of the ages of the rocks, lithology of rock layers, macroseismic values of scenario earthquake (Mw=6.8), and magnetic properties of rocks with each other. Identification of the sediment types, thickness of layers, and magnetic susceptibility of rocks were determined by using the respective published papers (Исрафилбеков и др., 1983; Babayev et al., 2020; Hrouda et al., 2009). We attempted to find any relation between parameters of seismic effects and magnetic properties of rocks through analysis of surface peak ground acceleration (PGA), intensity of shaking, soil amplification factor, and rocks' magnetic susceptibility.

Google Earth system was utilized to define the basemap for this research which consequently was meshed into 39 cells with a step 5km×5km grid (Fig. 1) (Google maps, 2024).

Fig. 1. The map of Azerbaijan with the rectangle showing the study area

Macroseismic parameters (magnitude, focal depth) of the Caspian earthquake 25.11.2000, which is accepted in this study as a scenario, near-event earthquake, were used to calculate epicentral/hypocentral distances to each cell of the study area from epicenter of the scenario earthquake (Fig. 2) and consequently to compute bedrock peak ground acceleration (PGA) under each cell and consequently, at the surface of those cells.

Table 1 demonstrates rocks' magnetic susceptibility values. Those values were analyzed and estimated from magnetic well logging data, the wellbores of which are illustrated in Fig. 3.

Consequently, magnetic susceptibility values of rocks were utilized to map the study area in terms of their distribution (Fig. 4).

Peak ground acceleration (PGA) was computed to evaluate the anticipated ground motion at both bedrock and surface level with 1D site effects of lithological layers. The expected bedrock PGA was estimated considering near-event earthquake parameters (magnitude, focal depth) by ground motion prediction equation (GMPE) (1).

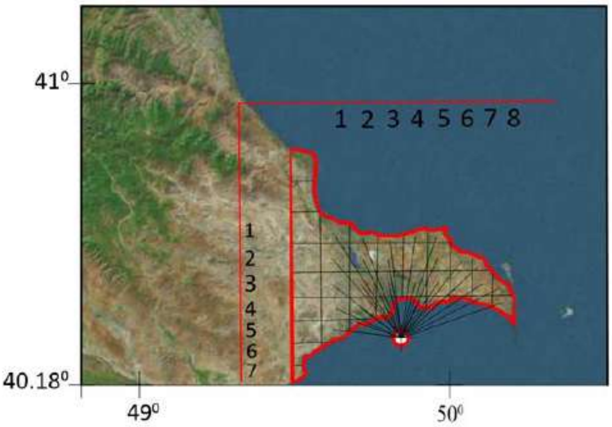

Fig. 2. Meshing of the study area.
Near-event scenario earthquake (accepted as Mw=6.8, focal depth h=35 km) is demonstrated by a circle. Numbers beyond the meshing area were used to enumerate cells

Table 1

Magnetic susceptibility values
in Absheron peninsula for each layer

Cell number	Area	Magnetic susceptibility	Rock type
4.4	Zigh	0.5-1.0	shale
		0.3-0.5	sandstone
		0.1-0.3	limestone
		0.01-0.1	marl
4.7	Zire	0.5-1.0	shale
		0.3-0.5	sandstone
		0.1-0.3	limestone
		0.01-0.1	marl
3.5	Surakhani	0.01 - 0.1	shale
		0.01 - 0.1	marl
		0.01 - 0.1	sandstone
		0.001 - 0.01	limestone
		0.001 - 0.01	granite
2.4	Ramani	0.01 - 0.1	sandstone
		0.01 - 0.1	shale
		0.01 - 0.1	marl
		0.001 - 0.01	limestone
5.2	Bibiheybat	0.01 - 0.1	sandstone
		0.01 - 0.1	shale
		0.01 - 0.1	marl
		0.001 - 0.01	limestone
3.4	Ahmadli	0.01 - 0.1	shale
		0.01 - 0.1	marl
		0.01 - 0.1	sandstone
		0.001 - 0.01	limestone
4.2	Lokbatan	0.5 - 1.0	marl
		0.07 - 0.5	shale
		0.03 - 0.1	sandstone
		0.02 - 0.05	limestone
4.5	Hovsan	0.02 - 0.05	limestone
		0.03 - 0.1	sandstone
		0.07 - 0.5	shale
		0.5 - 1.0	marl

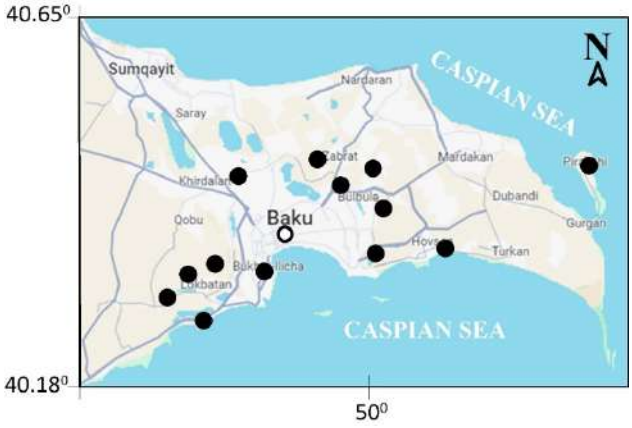

Fig. 3. Dots of magnetic well logging data across Absheron peninsula

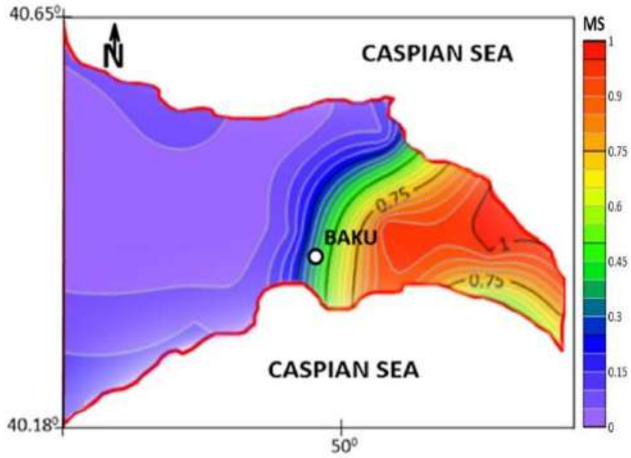

Fig. 4. Distribution of magnetic susceptibility of rocks in Absheron peninsula.
Note: MS indicates magnetic susceptibility

In (1) A is peak ground acceleration (in Gal = 10^{-2} m/s^{-2}), M is the magnitude and R is the hypocentral distance (in km):

$$lg\, A = 0.28M - 0.8\, lg\, R + 1.7 \qquad (1)$$

The Equation (1), an empirical function to compute PGA (Аптикаев и Копничев, 1979), the amplitude of ground motion, is the best-fitting empirically-derived equated function for predicting ground motion for Azerbaijan and, therefore, for the study region (Babayev et al., 2020).

Several studies concluded that shear wave velocity was an important parameter for evaluating the dynamic behavior of soil in the subsurface depth (Kanli et. al., 2006, 2008; Panza et al., 2011). Subsurface shear wave velocity values are significant in calculating seismic hazards (Kanlı et al., 2010; Panza et al., 2011).

The estimation of shear wave velocity (V_s) was derived from an empirical relation (2) with the P-wave velocity (V_p value). V_p value was measured for the specific soils by experimental method (Seed et al., 1969).

$$V_s = V_p/(4.34 - 0.49V_p) \qquad (2)$$

Furthermore, the amplification factor of soil for soft rocks in a subsurface layer was estimated from shear-wave velocities, density, and thickness of the layer using the SHAKE software (Ordonez, 2000) and for hard sedimentary rocks, the amplification factor within a layer has been calculated by using the Eq. (3) using shear-wave velocity (Midorikawa et al., 1992):

$$lg\, A_{AMP} = 1.11 - 0.42\, lg\, V_s \qquad (3)$$

The geological analysis in terms of rock ages and lithology of rock layers was generalized in the subsurface models used in our study in the calculation of the amplification factor of each layer (Table 2). We have calculated time domain peak ground acceleration based on the synthetic accelerograms obtained from the hypothetic earthquake data and respective parameters for all subsurface models. Fig. 5 shows the time domain parameters for eight different subsurface models.

Knowing amplification factor of layers from bedrock up to the surface soil of the Absheron peninsula through subsurface ground thus, the amplification factor for the whole cross-section, the peak ground acceleration (PGA) at surface and the intensity of shaking were computed, providing a comprehensive assessment of seismic effect of the earthquake. The peak ground acceleration (PGA) at the surface was computed through the following equation:

$$A_{SR} = A_{BR} * A_{AMP} \qquad (4)$$

where, A_{SR} is the surface PGA (in gal =10^{-2} m/s^{-2}), A_{BR} is the peak ground acceleration at bedrock (in Gal = 10^{-2} m/s^{-2}), A_{AMP} is the amplification factor.

The surface peak ground acceleration was compared with the intensity values using the correlation scale (Table 3) (Murphy and O'brien, 1977; Trifunac and Brady, 1975).

Table 4 demonstrates the seismic effect values computed from the near-event scenario earthquake parameters. The computation utilized the surface peak ground acceleration (PGA) (Table 4, (10)) and the predicted earthquake intensity (Table 4, (11)) as finals to simulate the peninsula.

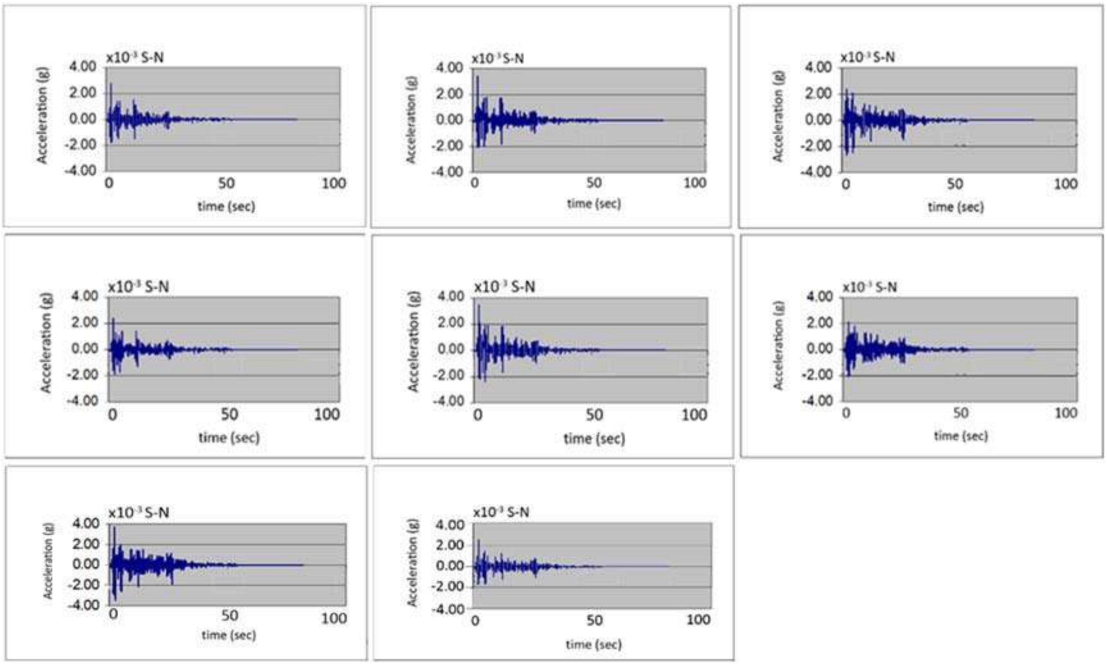

Fig. 5. Simulated time domain PGA based on best-fitted scenario for subsurface models (from above left to the left below: B5, C1, C3, C4, C6, E2, E5, E6)
Note: see Table 2 for the subsurface model description

Table 2

Subsurface lithological-geological models for the Absheron peninsula

Model	Thickness of sediments (m)	Age	Lithology
B5	20 110 1960	Q Q N	sands, clay, limestone clays sands, sandstone, carbonated clays
C1	4 5 20 3800	Q Q Q N	sand, gravel-pebble clay, argillaceous sand clay clay, sand, argillaceous sandstone and limestone
C3	12 20 1500	Q Q N	limestone clay, sand, limestone argillaceous limestone and sandstone
C4	5 5 20 1910	Q Q Q N	sand with sandstone sand, clay, sandstone sand, clay, sandstone sand, sandstone, organic clay
C6	160 120 1960	Q Q N	sands, clay, limestone clays sands, sandstone, carbonated clays
E2	60 290 1960	Q Q N	sands, sandstone sands, clay, limestone sands, sandstone, carbonated clays
E5	5 150 120 1960	Q Q Q N	sands sands, clay, limestone clays sands, sandstone, carbonated clays
E6	5 10 270 1960	Q Q Q N	limestone sands sands, clays, limestone sands, sandstone, carbonated clays

Note: Q – Quaternary; and N – Neogene

Table 3

Conversion between PGA (gal) and intensity (MSK-64) (Murphy and O'brien, 1977; Trifunac and Brady, 1975)

PGA gal	5–12	12–25	25–50	50–100	100–200	200–400
MSK-64	4	5	6	7	8	9

Table 4

Parameters of seismic effect for the near-event earthquake with macroseismic values of the event used for simulation of the surface peak ground acceleration and intensity

N (1)	Cell (2)	M (3)	H(km) (4)	The epicentral distance (km) (5)	R(km) (6)	PGA bedrock (Gal) (7)	Average ground type (8)	Amplification Factor (9)	PGA surface (Gal) (10)	MSK-64 (11)
1	1.1	6.8	35	43	55.44	161.78	clay	1.10	177.96	8
2	1.2	6.8	35	36	50.20	175.13	sand	1.10	192.65	8
3	1.3	6.8	35	34	48.79	179.18	sand	1.10	197.10	8
4	1.4	6.8	35	35	49.49	177.15	sand	1.10	194.86	8
5	1.5	6.8	35	37	50.93	173.15	solid and semi-solid rocks	0.57	98.69	7
6	2.1	6.8	35	39	52.40	169.25	clay	1.10	186.17	8
7	2.2	6.8	35	31	46.75	185.41	clay	0.76	140.91	8
8	2.3	6.8	35	27	44.20	193.92	clay	0.76	147.38	8
9	2.4	6.8	35	26	43.60	196.07	clay	0.95	186.26	8
10	2.5	6.8	35	28	44.82	191.78	solid and semi-solid rocks	0.53	101.64	8
11	2.6	6.8	35	32	47.42	183.32	solid and semi-solid rocks	0.53	97.16	7
12	2.7	6.8	35	37	50.93	173.15	sand	0.53	91.77	7
13	3.1	6.8	35	36	50.20	175.13	clay	1.10	192.65	8
14	3.2	6.8	35	25	43.01	198.21	clay	0.76	150.64	8
15	3.3	6.8	35	19	39.82	210.80	clay	0.53	111.73	8
16	3.4	6.8	35	18	39.35	212.80	clay	0.53	112.79	8
17	3.5	6.8	35	23	41.88	202.48	clay	0.53	107.32	8
18	3.6	6.8	35	28	44.82	191.78	solid and semi-solid rocks	0.53	101.64	8
19	3.7	6.8	35	32	47.42	183.32	solid and semi-solid rocks	0.53	97.16	7
20	3.8	6.8	35	38	51.66	171.18	sand	0.57	97.57	7
21	4.1	6.8	35	31	46.75	185.41	clay	1.10	203.95	9
22	4.2	6.8	35	22	41.34	204.60	clay	1.10	225.06	9
23	4.3	6.8	35	13	37.33	221.97	solid and semi-solid rocks	0.57	126.52	8
24	4.4	6.8	35	14	37.69	220.27	clay	1.10	242.30	9
25	4.5	6.8	35	15	38.07	218.50	sand	0.53	115.81	8
26	4.6	6.8	35	23	41.88	202.48	sand	1.10	222.73	9
27	4.7	6.8	35	30	46.09	187.52	clay	1.10	206.28	9
28	4.8	6.8	35	38	51.66	171.18	sand	1.10	188.30	8
29	5.1	6.8	35	21	40.81	206.70	clay	1.10	227.36	9
30	5.2	6.8	35	31	46.75	185.41	sand	1.10	203.95	9

The investigated parameters (Table 4, (10), (11)) were plotted for the study area, and their distribution patterns are illustrated in Fig. 6 and 7, respectively.

As a part of the comprehensive analysis, magnetic susceptibility, surface peak ground acceleration (PGA), and intensity maps were simulated (Fig. 8, 9). These models allowed us to correlate magnetic susceptibility, surface peak ground acceleration (PGA), and intensity values.

Results and discussions

The simulation of magnetic susceptibility distribution across the study area and the predicted intensity map of the scenario earthquake with hypothetic magnitude 6.8 allowed conducting a correlation between high-intensity zones of VIII-IX and high magnetic susceptibility values of 0.5-1.0 observed in the eastern part, extensively in the northeastern, southeastern parts of the Absheron peninsula, especially in the populated areas of Mardakan, Bulbule, and Dubandi.

Furthermore, the simulation of magnetic susceptibility and surface peak ground acceleration (PGA) distribution maps allowed conducting a correlation between high surface PGA and high magnetic susceptibility of rocks observed specifically in the populated settlements of Turkan, Bulbule, Hovsan, Dubandi in the eastern, southeastern, northeastern parts of the Absheron peninsula where 200-250 Gal surface PGA coincided with 0.5-1.0 magnetic susceptibility values.

Based on this current study, the eastern, southeastern, and northeastern parts of the Absheron peninsula are prone to high intensity of shaking (VIII-IX) and extensively surface peak ground acceleration (200-250 Gal). The magnetic susceptibility of rocks exhibits high values of 0.5-1.0.

The magnetic susceptibility of a rock depends on the type and abundance of magnetic minerals it contains (Awad et al., 2023). The high value of magnetic susceptibility indicates a high abundance of magnetic minerals, while a low magnetic susceptibility value indicates a low abundance of magnetic minerals in rock samples (Siregar et al., 2022).

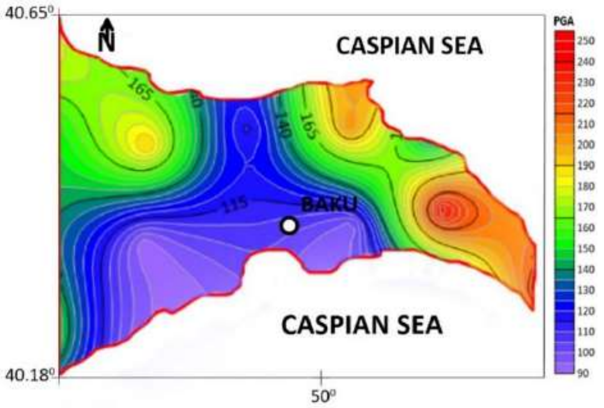

Fig. 6. Distribution of the surface peak ground acceleration (PGA) for a near-event earthquake scenario

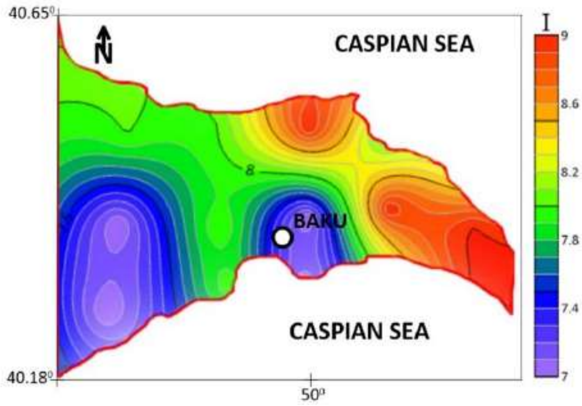

Fig. 7. Intensity (I) distribution for a near-event earthquake scenario

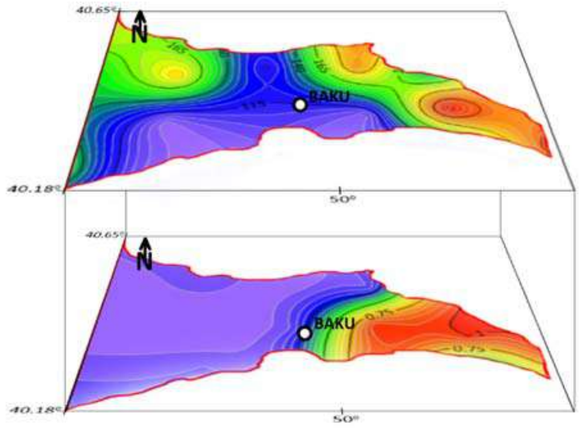

Fig. 8. Simulation of surface peak ground acceleration (PGA) and magnetic susceptibility of the study area (upper one is the distribution of surface peak ground acceleration (PGA) for the near-event earthquake scenario, lower one is the distribution of magnetic susceptibility of rocks)

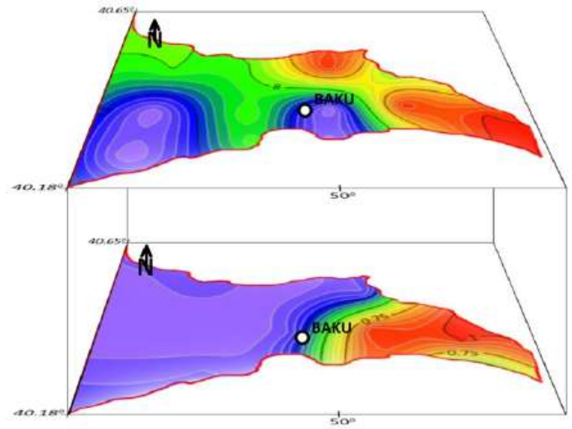

Fig. 9. Simulation of intensity and magnetic susceptibility of the study area (the upper one is intensity distribution for the near-event earthquake scenarios, lower one is a distribution of magnetic susceptibility of rocks)

Theoretically, the high magnetic susceptibility values in the eastern, southeastern, and northeastern parts of the peninsula might indicate the abundance of the sporadic existence of magnetic minerals in the sandstone, limestone, marl, and shale rock formations.

Rocks can also be categorized on their magnetic susceptibility values: any mineral with a positive magnetic susceptibility value is paramagnetic, while a negative magnetic susceptibility value corresponds to a diamagnetic mineral (Elsayed et al., 2021). Among the most common minerals that pose paramagnetism in rocks are illite, pyrite, chamosite, chlorite, and celadonite, which are usually found in sandstone and shale formations (Elsayed et al., 2021)**.** Shales, a mixture of clay and carbonate minerals, represent 2/3 of the sedimentary rocks on Earth with a magnetic mineral group which, at first order, appears simple with ferrimagnetic iron oxides as the main magnetic mineral group present (Kars et al., 2023). Based on the findings they presented, we assume that these mineral compositions of the rock layers might amplify shear wave velocity in the eastern part, extensively in the northeastern and southeastern parts of the Absheron peninsula.

For this study, the amplification factor of soil for soft rocks in a subsurface layer was computed through shear-wave velocities, density, and thickness of the layers. It is assumed that this rock formation with high magnetic susceptibility values affect the amplification factor of soil, specifically in the eastern part, southeastern, and northeastern parts of the Absheron peninsula. Thus, it causes high surface peak ground acceleration values, consequently, compared intensity of shaking.

As a consequence, this current study permits to claim that there is an existing direct, physical relation between surface peak ground acceleration, the intensity of shaking of the earthquake, and magnetic susceptibility of rocks. High surface peak ground acceleration (PGA) and magnetic susceptibility values coincided and demonstrated convergence in the eastern, southeastern, and northeastern parts of the peninsula including areas of Hovsan, Turkan, Bulbule, Mardakan, and Dubandi. The same convergence was demonstrated in the eastern, southeastern, and northeastern parts of the peninsula between the magnetic susceptibility values and predicted seismic intensity of shaking.

As a result, rocks with high magnetic susceptibility values will be characterized by a high trend of earthquakes' seismic effect parameters in terms of peak ground acceleration and intensity of shaking.

Conclusions

This research aimed to model earthquake hazard assessment for the Absheron peninsula by integrating magnetic properties of rocks regarding magnetic susceptibility with seismic effect parameters: computed surface peak ground acceleration (PGA) and intensity of shaking from a credible earthquake. The Baku-Caspian earthquake of 25.11.2000 with accepted moment magnitude Mw=6.8 was taken as a scenario earthquake near the investigated site and considered as a "near-event earthquake." The study analyzed the local site effects and computed soil amplification factors, revealing the variation of ground motion characteristics on the surface. The simulated models allowed revealing convergent correlations between values of magnetic susceptibility and seismic intensity of shaking in the eastern, southeastern, and northeastern parts of the peninsula. Specifically, areas with high seismic intensity of shaking (VIII-IX) coincided with high magnetic susceptibility values (0.5-1.0) in the eastern, southeastern, and northeastern areas. This technique permits disclosing convergence of investigated parameters in terms of magnetic susceptibility of rocks, surface peak ground acceleration (PGA), and seismic intensity of shaking computed by the scenario earthquake.

Consequently, we can conclude that rocks with high magnetic susceptibility values are interlinked with the seismic effect that an earthquake can produce depending on the shallow depth and high magnitude. We interpret this approach as an additional input towards improving seismic hazard assessment methods. This successful integration between seismic hazard and magnetic properties of rocks demonstrates productivity of interdisciplinary researches and indicates the need for integration of geophysical methods for future studies. The results can be served as an additional input in the studies of magnetic influence on the earthquakes and the researches of the relationship between the magnetic perturbations and seismic responses.

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МОДЕЛИ СЕЙСМИЧЕСКОЙ ОПАСНОСТИ АБШЕРОНСКОГО ПОЛУОСТРОВА С УЧЁТОМ МАГНИТНЫХ СВОЙСТВ ГОРНЫХ ПОРОД

Бабаев Г.Р.[1,2], Алиев З.В.[1]
[1]*Министерство науки и образования Азербайджанской Республики, Институт геологии и геофизики, Азербайджан*
AZ1143, Баку, просп. Г. Джавида, 119
[2]*Азербайджанский Государственный Университет нефти и промышленности, Азербайджан*
AZ1010, Баку, просп. Азадлыг, 20

Резюме. Разработана модель опасности землетрясений по вариациям магнитной восприимчивости горных пород, интегрирующим с макросейсмическими параметрами достоверного землетрясения, с учетом динамики площадных эффектов, примененная для Абшеронского полуострова (Азербайджан). Также были использованы данные магнитного каротажа, литологические и геологические карты Абшеронского полуострова, сейсмические каталоги. Максимально ожидаемое движение грунта на Абшероне рассчитано для неглубокого Баку-Каспийского землетрясения 25.11.2000 г. вблизи зоны исследования, которое отмечено как сценарий «близкого землетрясения» и рассматривается как достоверное землетрясение с моментными магнитудами Mw=6.18 и Mw=6.08. В данном исследовании моментная магнитуда принята равной Mw=6.8. Оценка воздействия на территорию проводилась путем детальной геотехнической обработки грунтовых условий от нижележащих слоев до земной поверхности с использованием одномерного (1-D) анализа отклика грунта с помощью SHAKE2000. Мы оценили реакцию слоев грунта на землетрясение, рассчитав усиление амплитуды сейсмической волны и изменение характеристик колебания земной поверхности. На основе параметров сценария землетрясения рассчитано пиковое ускорение земной поверхности, скоррелировано с интенсивностью MSK-64. Проведено моделирование параметров ускорения грунта, сейсмической интенсивности и магнитной восприимчивости. Северо-восточная и юго-восточная части полуострова характеризуются пиковым ускорением грунта 165-250 гал и интенсивностью VIII-IX, что на 31% и 49% выше сейсмической опасности в тех же значениях по сравнению с другими частями. Для восточной части магнитная восприимчивость изменяется в пределах 0.5-1.0. Эти значения указывают на отчетливую связь вариаций магнитного поля с сейсмическим эффектом землетрясений. Наш подход вносит существенный вклад в совершенствование существующих методов оценки сейсмической опасности.

Ключевые слова: *Азербайджан, Абшеронский полуостров, сейсмическая опасность, пиковое ускорение грунта, интенсивность, магнитная восприимчивость, моделирование*

ABŞERON YARIMADASI ÜÇÜN SÜXURLARIN MAQNİT XASSƏLƏR İLƏ ƏLAQƏDAR OLAN ZƏLZƏLƏ TƏHLÜKƏSİ MODELLƏRİ

Babayev Q.R.[1,2], Əliyev Z.V.[1]
[1]*Azərbaycan Respublikasının Elm və Təhsil Nazirliyi, Geologiya və Geofizika İnstitutu, Azərbaycan*
AZ1143, Bakı, H. Cavid prosp., 119
[2]*Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan*
AZ1010, Bakı, Azadlıq prosp., 20

Xülasə. Abşeron yarımadası timsalında (Azərbaycan) qrunt təsirinin dinamikası nəzərə alınmaqla, baş vermiş zəlzələnin makroseysmik parametrləri (maqnituda, dərinlik, coğrafi yerləşmə, episentral məsafə) ilə süxurların maqnit həssaslığının qiymətlərini inteqrasiya edilərək zəlzələ təhlükəsinin qiymətləndirilməsi üçün modellər qurulmuşdur. Quyuların maqnit karotaj məlumatlarından, ərazinin litoloji və geoloji xəritələrindən, yerli və beynəlxalq seysmik kataloqlardan istifadə edilmişdir. Abşeron üçün qruntun gözlənilən maksimal hərəkəti, 25.11.2000-ci ildə baş vermiş ərazinin yaxınlığındakı dayaz Bakı-Xəzər zəlzələsi üçün hesablanmışdır ki, bu da tədqiqatda ssenar "yaxın zəlzələ" kimi qəbul olunur və Mw=6.18 və 6.08 maqnitudalı mümkün olan zəlzələ kimi sayılır. Tədqiqatda moment maqnitudası Mw=6.8 qiymətində istifadə olunub. Qrunt təsirinin qiymətləndirilməsi SHAKE 2000 proqram təminatı ilə birölçülü (1-D) qruntun effekt analizindən istifadə etməklə ana süxurdan səthə qədər ətraflı geotexniki cəhətdən xarakterizə olunaraq həyata keçirilmişdir. Beləliklə, seçilmiş zəlzələlərin süxur laylarına təsiri təyin edilmiş, qruntun seysmik dalğa amplitudasının güclənmə əmsalı hesablanmış və səthdə yerin hərəkət xüsusiyyətlərinin dəyişməsi müəyyənləşdirilmişdir. Ssenar zəlzələnin parametrlərinə əsasən, yer səthində qruntun maksimal təcili (QMT) vahidləri hesablanmış, MSK-64 intensivlik şkalası üzrə korrelyasiya olunmuşdur və nəticə olaraq, tədqiqat ərazisi üçün qruntun təsiri ilə səthdə qruntun maksimal təcili (QMT), intensivlik və maqnit həssaslığının qiymətləri modelləşdirilmişdir.

Nəticələr göstərir ki, Abşeronun şimal-şərq və cənub-şərq hissələrində qruntun maksimal təcili 165-250 qal və VIII-IX intensivlikdə təyin edilmişdir ki, bu da yarımadanın qərb hissələri ilə müqayisədə həmin qiymətlərdəki seysmik təhlükədən 31% və 49% yüksəkdir. Yarımadanın şərq hissəsi üçün maqnit həssaslığı 0.5-1.0 arasında dəyişir. Bu qiymətlər, maqnit sahəsindəki dəyişikliklərin zəlzələlərin seysmik təsiri ilə mövcud fərqli əlaqəsini göstərməyə imkan verir. Təklif etdiyimiz yanaşma seysmik təhlükənin qiymətləndirilməsində mövcud metodların təkmilləşdirilməsinə mühüm töhfə verir.

Açar sözlər: *Azərbaycan, Abşeron yarımadası, zəlzələ təhlükəsi, qruntun maksimal təcili, intensivlik, maqnit həssaslığı, simulyasiya*