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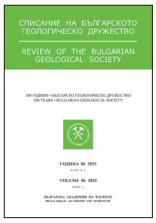

Dependence of neodeterministic seismic acceleration modelling on seismogenic faults parameters: a case study for the city of Plovdiv, Bulgaria

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Abstract. This study aims to generate a set of synthetic accelerograms for the seismic station Plovdiv, varying parameters of the seismic sources near Plovdiv. The goal is to evaluate the maximum ground accelerations expected during future events along adjacent faults. We use the XeRiS software to calculate synthetic accelerograms and evaluate the maximum ground accelerations varying several parameters: fault's strike, dip and rake; depth and magnitude of the event and distance to the specified site. The accelerograms were computed by discrete wave number technique considering also the near field terms using double-couple point source. Seismogenic faults parameters were selected according to the EDSF database. Our results confirm that highest seismic hazard for Plovdiv pose the western segment of the Plovdiv fault, as well as the Asenovgrad fault. We also identify certain directivity effects, favorable for earthquakes on the western part of the Plovdiv fault and on the Chirpan fault, but unfavorable for earthquakes on the Asenovgrad fault.

Keywords: focal mechanism, fault parameters, seismogenic faults, Plovdiv Region, ground motion modelling.

Introduction

Plovdiv is the second largest Bulgarian city, with a concentration of population, industry, and cultural heritage. Thus, seismic hazard evaluation for Plovdiv is of societal importance. The Plovdiv region in Bulgaria was affected by two devastating earthquakes in 1928: one along the Chirpan fault on April 14th with a magnitude of 6.8, followed a few days later, on April 18th, by a second one along the Plovdiv fault with a magnitude of 7.0 or 7.1 according to different studies (Shebalin et al., 1998; Christoskov, 2005; Dimitrov et al, 2020) and an epicenter near Popovitza. Alongside the Plovdiv fault and the Chirpan fault, there are two other seismogenic faults near Plovdiv: the Asenovgrad and Choba faults (Basili et al., 2013). A strong earthquake, with magnitude estimates up to 7.2, occurred in 1750 near Plovdiv, with an epicenter along the Asenovgrad fault (Ambraseys, 2009; Shebalin et al., 1998).

In a recent paper (Dimova et al., 2025), using a neodeterministic seismic hazard approach, ground motion acceleration and response acceleration spectra are estimated for a selected location in Plovdiv. Numerous possible earthquake scenarios along each of the above-mentioned faults are considered, seismic wave propagation for each scenario is modelled, and the corresponding composed synthetic accelerogram spectra for the chosen location are assembled. The main findings are that highest seismic hazard for Plovdiv is related to events along the western part of the Plovdiv fault as well as along the Asenovgrad fault.

This paper presents an extension of the study of Dimova et al. (2025). Here we generate a set of synthetic accelerograms for a location coinciding with the seismic station PLD (Plovdiv), varying parameters of the seismic sources (faults) near Plovdiv. The goal is to evaluate the maximum ground motion acceleration expected during fu-

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ture events along these faults and to study its dependence on the seismogenic faults parameters. The location of the seismic station PLD was selected in order to fasilitate the comparison between real and synthetic seismograms for a possible future prognosis of strong earthquake in the area.

Data and method

To calculate ground acceleration time histories for the selected location we use neodeterministic modelling approach (Panza, Bala, 2020; Panza et al., 2019), involving a discrete wave number technique and considering also the near field terms, using double-couple point source and the Xeris software application developed at the University of Trieste, Italy (Vaccari, Magrin, 2022). The seismogenic faults in the considered region are modelled as extended sources with focal mechanism and maximum magnitude estimates (Table 1) obtained from the European Database of Seismogenic Faults (EDSF, Basili et al., 2013; downloaded from https://edsf13.ingv.it/map/sharedata). A number of earthquake scenarios are calculated for each seismogenic fault, varying the focal mechanism parameters (fault, dip, strike), the earthquake magnitude, the source depth and the epicentral distance. For each earthquake scenario, 100 modelled spectra realizations are calculated. The rupture process is modelled by an algorithm based on the approach proposed by Gusev (2011).

To model the seismic waves propagation, we use depth-velocity structure model for the Plovdiv region based on local lithosphere velocity model (Raykova, Panza, 2015; Raykova et al., 2019) and a local geology map (Kozhuharov et al., 1999). More details on the depth-velocity model used are given by Dimova et al. (2025). Finally, we obtain ground motion acceleration time histories at the selected location (Fig. 1a), coinciding with the seismic station PLD (Plovdiv) for each earthquake scenario and estimating the influence of the fault parameters on the ground acceleration. For this purpose, we fix 5 of the following parameters – strike-receiver angle, dip, rake, magnitude, epicenter distance, and source depth – and vary the sixth one, estimating the maximum ground acceleration.

Results and discussion

First, we consider model simulations for the Plovdiv fault, the largest seismogenic fault near the city of Plovdiv. According to the EDSF database, maximum magnitude 7.1 is expected for this fault. Due to its long length, it is highly unlikely the entire Plovdiv fault to rupture simultaneously during a 7.1 magnitude earthquake. Instead, a scenario involving rupturing of less than half of the fault length is more probable, as is the case of the 1928 Popovitsa earthquake. Moreover, strong events along the eastern part of the Plovdiv fault are less dangerous for the city of Plovdiv, while strong events along the western part of the fault may be devastating for the city. Thus, we consider two groups of earthquake scenarios:

(1) scenarios involving the entire Plovdiv fault and for the related simulations we use an epicentral distance of 60 km corresponding to the distance between the selected receiver location, and the geometric center of the fault;

(2) scenarios, involving only the western half of the Plovdiv fault, where we use an epicentral distance of 28 km corresponding to the distance between the selected receiver location and the geometric center of the western half of the fault.

The strike-receiver angle, defining the azimuthal position of the location where the ground motion is to be obtained is 17.5 degrees for the simulations involving the entire fault, and 29.5 degrees for the simulations involving only its western segment. The strike-receiver angle is measured counterclockwise from the fault strike to the strike-receiver direction.

Table 1. Fault parameters for the seismogenic faults considered in this study

Parameter	Seismogenic fault			
	PLOVDIV	ASENOVGRAD	CHOBA	CHIRPAN
Depth (km)	0–15	1–15	1–10	0–15
Maximum Magnitude (M_w)	7.1	6.7	6.5	7
Strike (°)	275–310	280–300	80–105	90–105
Dip (°)	35–55	40–60	40–60	40–60
Rake (°)	280–310	270–300	270–290	270–290

For the other parameters, we use the estimates from the EDSF database.

In Figure 1, we present the parametric test results involving only the western half of the Plovdiv fault. Maximum ground accelerations for radial, transverse, and vertical ground motions are shown separately. All components vary significantly with the strike-receiver angle, especially the radial and vertical components, reaching values of up to 450 cm/s^2 for certain directions (Fig. 1b). However, for the direction towards the selected location in Plovdiv, corresponding to strike-receiver angle 29.5°, all acceleration components are close to minimum, about 200 cm/s^2. Thus, the selected location in Plovdiv is favorably situated in respect to the modelled source. The dip angle of the Plovdiv fault is about 45° (vertical line). For this dip angle, all three acceleration components are almost equal, about 200 cm/s^2

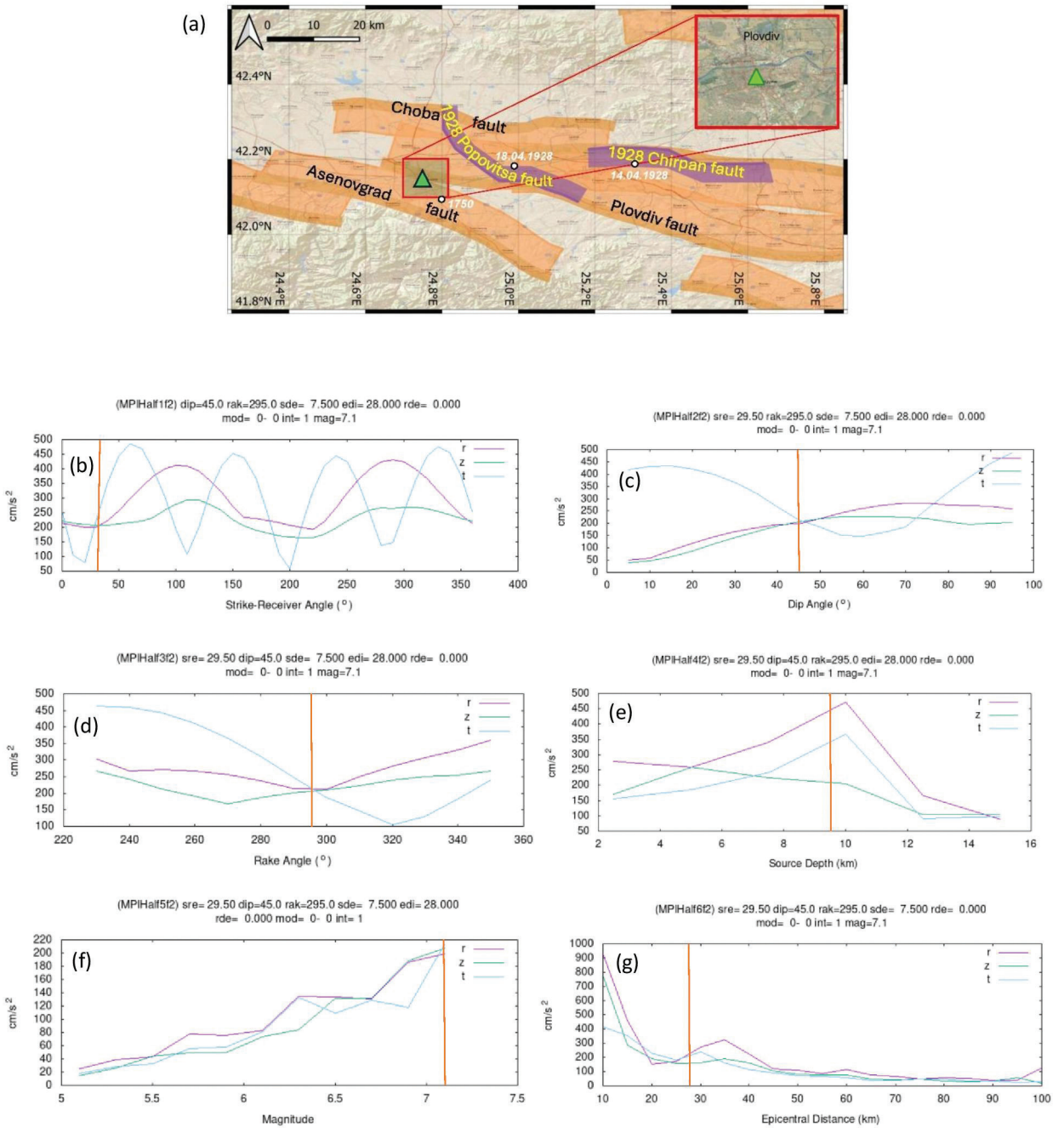

Fig. 1. (*a*) Seismogenic faults near Plovdiv and selected location where the ground motion acceleration is to be estimated; (*b–g*) Dependence of the maximum ground motion acceleration for the selected location on the (*b*) strike-receiver angle; (*c*) dip angle; (*d*) rake angle; (*e*) source depth; (*f*) magnitude; and (*g*) epicentral distance.

(Fig. 1c). For the rake angle (Fig. 1d), again all three maximum acceleration components reach comparable values of 200–250 cm/s^2 for rake values corresponding to the Plovdiv fault (vertical line). The transverse component varies significantly with the rake angle. For certain rake values it reaches values up to 450 cm/s^2, about twice as high as for the relevant Plovdiv fault rake. For magnitude 7.1 earthquakes, all maximum ground acceleration components (radial, transverse, vertical) are almost equal, about 200 cm/s^2, at the selected location (Fig. 1f). These are relatively moderate ground acceleration values for magnitude 7.1 earthquake, which is related to the favorable position of the PLD in respect to the fault geometry and seismic energy radiation pattern. For the western half of the Plovdiv fault earthquake scenarios, we use epicentral distance of 28 km corresponding to the distance between the selected location and the fault segment center. However, certain segments of the Plovdiv fault are even closer to the selected location and for earthquakes with epicenters along these segments, the corresponding maximum ground acceleration may be higher than for considered scenario. For simulations with an epicenter distance of 10 km, we obtain maximum ground acceleration values of about 900 cm/s^2 for the radial motion, 800 cm/s^2 for the vertical motion, and 400 cm/s^2 for the transverse motion (Fig. 1g). For all components, maximum ground accelerations decrease strongly with epicentral distance in the distance range 10–20 km and more slowly for larger epicentral distances.

Earthquake rupture scenarios, involving the entire Plovdiv fault (not shown), show lower ground motion accelerations due to the larger epicentral distance used in the simulations. Relatively stronger radial ground motion acceleration, up to 300 cm/s^2, is obtained only for extremely shallow events with source depth of 1–3 km. At the selected location in Plovdiv, the radial and vertical components of the maximum ground accelerations are much higher than the transverse component.

Further on, we consider model simulations and parametric tests for the Asenovgrad fault (not shown). This fault is situated very close to the city of Plovdiv, thus posing a significant seismic risk. The epicentral distance used in the simulations is 8 km, equal to the distance from the selected location to the center of the Asenovgrad fault. Model simulations show that at epicentral distance 8 km, a magnitude 6.7 earthquake along the Asenovgrad fault gives rise to strong ground motion acceleration dominated by the radial component which varies with the strike-receiver angle from 1100 cm/s^2, up to almost 2500 cm/s^2. Moreover, in the direction towards the selected location in Plovdiv (strike-receiver angle 257°), the radial component is almost at its peak. The vertical component is also at its peak of about 1100 cm/s^2 in this direction. On the contrary, the transverse component is negligible in the same direction.

Modelled ground motion acceleration at the selected location in Plovdiv is lower for the Choba fault earthquake scenario than for the Plovdiv fault and Asenovgrad fault earthquake scenarios. For the direction towards the selected location in Plovdiv, all three ground motion acceleration components (radial, vertical, transverse) are equal and reach values up to 200 cm/s^2 at this location indicating moderate seismic hazard for Plovdiv.

For the Chirpan fault earthquake scenario, we obtain even lower maximum acceleration estimates for the selected location in Plovdiv, tens of cm/s^2. All three maximum acceleration components (radial, vertical, transverse) are again equal, as for the Choba fault case. The low seismic hazard for Plovdiv posed by the Chirpan fault is related not only to the large epicentral distance but also to directivity effects. For strike-receiver angle 193°, corresponding to the direction towards Plovdiv, all three maximum acceleration components (radial, vertical, transverse) are close to minimum.

Conclusions

In this paper, we consider several earthquake scenarios posing seismic risk for the city of Plovdiv, Bulgaria, related to the nearby seismogenic faults. We study how the expected ground motion acceleration depends on the fault's parameters for the Plovdiv fault, Asenovgrad fault, Choba fault, and Chirpan fault. Our results confirm that highest seismic hazard for Plovdiv pose the western segment of the Plovdiv fault, as well as the Asenovgrad fault. We identify certain directivity effects. The selected location, representative for Plovdiv, is favorably situated in relation to earthquake scenarios on the western half of the Plovdiv fault and on the Chirpan fault. On the other hand, for the Asenovgrad earthquake scenario, highest ground motion acceleration is observed for the direction towards the selected location in Plovdiv.

Our results contribute to a better understanding of the seismic risk for the large Bulgarian city of Plovdiv.

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