Soil Dynamics and Earthquake Engineering 99 (2017) 20–34

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Seismic hazard analysis using simulated ground-motion time histories: The case of the Sefidrud dam, Iran

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ARTICLE INFO

Keywords:
Probabilistic seismic hazard analysis
Sefidrud dam
Background seismicity
Strong motion
Hybrid broadband simulation
Near-field

ABSTRACT

This study aims at conducting probabilistic seismic hazard analysis for the Sefidrud dam located near Rudbar City. For this purpose, firstly, the characteristic earthquake recurrence model for major earthquakes on individual main faults have been combined with the smaller (smoothed) background seismicity of the region. Then, appropriate ground motion prediction equations were applied to estimate hazard values. Finally, in order to obtain reliable estimation of seismic hazard due to sources close to the dam site and to investigate near-field characteristics of motion, the Rudbar fault as the most prominent earthquake source in the immediate vicinity of the site is considered in seismic hazard computation using hybrid broadband simulation based ground motion parameters.

The results of this method with different declustering schemes are reported for two level of seismic hazard analysis (i.e. return periods of 475 and 2475 years). Best estimate seismic hazard maps of PGA and PGV values obtained from the logic tree method is presented. By inclusion of simulation results for the Rudbar fault in the probabilistic seismic hazard analysis (PSHA), maximum PGA and PGV for 475 years return period obtained around 340 cm/s/s and 25 cm/s, respectively. For classic PSHA without including simulation the maximum PGA and PGV for 475 years return period obtained around 450 cm/s/s and 32 cm/s, respectively. With the simulation-based PSHA for a 2475 years return period a maximum PGA of 650 cm/s/s and PGV of 50 cm/s have been estimated. Classic PSHA (without simulation) for a 2475 years return period has resulted a maximum PGA of 850 cm/s/s and PGV of 65 cm/s.

1. Introduction

The Rudbar strike-slip fault lies in the Alborz Mountains. The Alborz forms a high curve of mountains from the southern end of the Talesh (~37°N49°E) to their intersection with the Kopeh Dag at about 56°E. No earthquakes deeper than 30 km is reported correctly in the Kopeh Dag, Alborz and Talesh, which limited to the northeast, south and west sides of the South Caspian Basin (beneath the central Caspian Sea). The Rudbar fault is situated over 2,000 m from sea level, and close to the crest of the western Alborz [1] (Fig. 1).

The Rudbar earthquake is one of four large magnitude events occurred in this part of the Alborz during the instrumental period (Table 1). The damage distribution of the Polrud-Tonekabon earthquake suggests the east–west Kelishom left-lateral fault, which is located east of the Rudbar fault, as a possible source. The Rudbarat-Taleqan earthquake may have ruptured the Alamutrud fault farther east. Apparent left-lateral river displacements of ~200 m on the Kashachal fault and up to ~1.5 km of the Kelishom fault, which are situated at the eastern end of the Rudbar fault [2].

The Rudbar earthquake of the 20 June 1990 with moment magnitude of 7.30 and a seismic moment of 1.4×10^{20} N. m(total left-lateral displacements are a maximum of ~1 km) was the most catastrophic earthquake occurred in northern Iran. The study of Iranian historical earthquakes confirms occurring destructive seismic events in this region during historical times [2–7]. In Table 1 is summarized three historical events struck the vicinity of Rudbar with their causative faults. These earthquakes with the surface magnitude ranging from 7.2 to 7.7 are comparable to the Rudbar earthquake [5].

According to Campos et al. [45]: "Several authors have reported that the body-wave signals for the Rudbar earthquake indicated that rupture was very complex. For example, Berberian, Qorashi, Jackson, Priestley and Wallace [5] quote an unpublished work by Gao and Wallace (1992)

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http://dx.doi.org/10.1016/j.soildyn.2017.04.017
Received 22 August 2016; Received in revised form 9 April 2017; Accepted 19 April 2017
0267-7261/

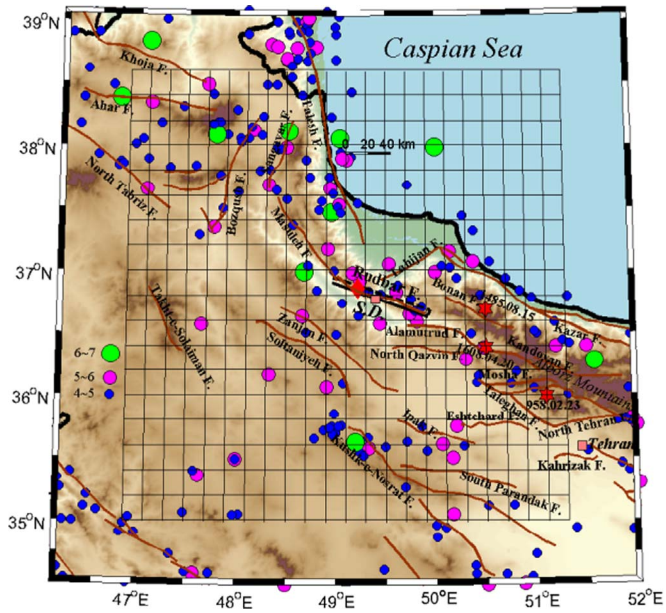

Fig. 1. The seismic sources in the Rudbar and surrounding provinces. The color scheme reflects topography, with light brown color denotes low elevation and dark brown color denotes mountains. The black rectangles are the 396 cells that were considered as the background seismic sources. The red lines show the main faults of the studied region. Stars are the location of large historical earthquakes [1,2]. Circles represent instrumental seismicity [3,4]. F: Fault. S.D: Sefidrud dam.

Table 1
Historical seismicity within a 150-km radius around the epicentral area of the Rudbar earthquake [5,2].

Date	Latitude	Longitude	MMI	M_s	Epicentral Region
958.02.23	36.0	51.1	X	~7.7	Rey-Taleqan
1485.08.15	36.7	50.5	IX	~7.2	Polrud-Tonekabon
1608.04.20	36.4	50.5	X	~7.6	Rudbarat-Taleqan

who proposed that the mainshock rupture consisted of at least three subevents in the first 20 s whereas the results of Thio, Satake, Kikuchi and Kanamori [8] indicated four subevents. The fault planes strike between 283° and 303° and have northward dips ranging from 54° to 82°".

The Rudbar earthquake with total casualties of about 100,000 people left more than 500,000 homeless and destroyed 3 cities including Rudbar, Manjil and Lowshan as well as 700 villages around these cities. During this earthquake 300 more villages in the Gilan and Zanjan province were significantly damaged and nearly 100,000 buildings lost their functionality. Moreover, the earthquake caused about 80 horizontal cracks along construction joints in the Sefidrud dam [2,5,9].

The region is a densely populated area with vital structures such as the Sefidrud dam. Moreover, according to the historical seismicity in the northern Iran, the Rudbar region is one of the most vulnerable areas in Iran and reliable estimation of seismic hazard is crucial to mitigate seismic risk in this region. The probabilistic seismic hazard analysis (PSHA) is often conducted to calculate seismic hazard in earthquake prone regions. Computational framework of PSHA considers all possible earthquake events to estimate ground shaking levels associated with its probability of exceedance. Despite of the simple theory behind this method it is widely accepted among practitioners as the most suitable and simplest approach to perform seismic hazard study [10].

PSHA can be done using time-dependent or time-independent probabilistic models. In the first model, time elapsed since last major earthquake is considered, whereas the second one assumes that events occur independently and uniformly in time. The time-dependent PSHA is suitable for regions where the time elapsed since the last earthquake is greater than the mean time interval [11]. In the Rudbar region the last major earthquake was the Rudbar earthquake of the 20 June 1990. Moreover, northern Iran is specified by the long seismic quiescence intervals ranging from a hundred to thousands of years. Therefore, it may be realistic to simply apply time-independent or Poisson model to perform PSHA (see Console, Murru and Falcone [12] for a similar case in Italy).

Therefore, in the current study the time-independent probabilistic seismic hazard analyses is conducted for the Sefidrud dam. The common practice in probabilistic seismic-hazard analysis is to consider characteristic earthquake distribution for line sources and exponential distribution for area sources (e.g., Kramer [13]). However, a large number of seismic hazard studies performed in Iranian plateau have treated faults as area sources by implementing the truncated exponential distribution for both line and area sources. This is largely because of the lack of sufficient data required to describe line sources (i.e. fault slip rates).

Here, first of all, characteristic earthquake distributions are assigned to all active faults around the epicentral area of the Rudbar earthquake. In fact, the recurrence interval and last historical event for a number of individual faults are estimated based on available paleoseismological, historical and archeoseismological data. Moreover, in the absence of the mentioned data the recently derived slip rates are applied to estimate the recurrence intervals (return period). Then, the characteristic earthquake model for major earthquakes on individual main faults have been combined with the smaller (smoothed) background seismicity of the region. After determination of suitable model for all seismic sources a set of reliable ground motion prediction equations (GMPEs) with equal weights were applied to estimate hazard values. However, it should be noted that vast majority of GMPEs are not well constrained in near-field sources due to lack of abundant near-field ground motion time histories. In other words, existing ground motion models do not take into account some crucial feature of fault rupture process that may significantly affect the results of seismic hazard analysis.

One of the solutions to overcome this deficiency is to simulate physics-based records so as to provide sufficient data for developing reliable GMPEs in near source region [14]. In this way, simulated broad-band time histories of ground motion put as an alternative input to the GMPEs [15]. Therefore, in the final step, following Villani, Demartinos, Vanini and Faccioli [15], ground motion time histories are simulated for the Rudbar fault as the most prominent earthquake source in the immediate vicinity of the city to combine deterministically computed ground motion parameters with PSHA result. The calculated ground motion parameters are due to some selected earthquake scenarios which were obtained with respect to recorded data during the Rudbar earthquake of the 20 June 1990.

2. Characteristic earthquake model for individual faults

In this section, it is tried to consider characteristic magnitude distribution for all major faults in the Rudbar region. To this end, the recurrence interval and last historical event for a number of individual faults are estimated based on available paleoseismological and archeoseismological studies. Moreover, in the absence of the mentioned studies, following the suggested approach in [16], earthquake recurrence interval is estimated from recently derived slip rates.

Table 2 taken from Zafarani, Hajimohammadi and Jalalalhosseini [17] provides required information to determine characteristic magnitude distribution for faults with available paleoseismological and archeoseismological data. In this table, column 1 specifies name of these faults while the second column determines fault length based on Hessami, Jamali and Tabassi [18] and Gholipour, Bozorgnia, Rahnama, Berberian and Shojataheri [19]. In column 3, characteristic magnitude of the faults are driven from Berberian [20], Berberian, Ghorashi, Arjangravesh and Mohajer Ashjaie [21] and Wells and Coppersmith