SEISMIC HAZARD ANALYSIS BASED ON PROBABILISTIC AND DETERMINISTIC METHODS
(CASE STUDY OF MOHAMMADABAD DAM SITE)

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ABSTRACT

The Mohammadabad dam site is located in the north of Iran in a region of high seismicity. A seismic hazard analysis was performed based on the most recent seismo-tectonic data to determine the design ground motion parameters. These parameters estimated four different design levels. The ground motion parameters for the Maximum Design Level (MDL) and Design Basis Level (DBL) were obtained from a probabilistic seismic hazard analysis (PSHA) whereas the MCL was derived from a deterministic analysis (DSHA). The PSHA followed the conventional pattern consisting of the following elements: (i) identification of the seismic sources within a certain radius from the site, (ii) definition of the seismicity through a recurrence relationship for each source using the Kijko-Sellevoll approach, (iii) selection of suitable attenuation relationships, and (iv) generating curves showing the probability of exceeding different levels of ground motion at the site during a specified period of time. For the DSHA, the characteristics of faults within the area of interest was assessed based on topographic, geologic and aeromagnetic maps, air photos, field investigation, and a comprehensive search in the literature. Results are presented in terms of peak ground acceleration (PGA) and acceleration response spectra.

Key Words:

Seismic hazard analysis, Fault, Seismo-tectonics, Design ground motion, Iran.

BODY OF PAPER:

INTRODUCTION

The Mohammadabad dam is located on Rudbar River in Golestan province, Iran (see Figure 1). This dam falls within a region of high seismicity, the Alburz seismo-tectonic provinces. In order to estimate the ground motion parameters a comprehensive seismic hazard analysis was performed. This paper gives first a brief overview of the seismo-tectonics of the region and the seismicity. The methodology followed to obtain the peak ground acceleration, response spectra and design accelerograms for different design levels is then described together with selected results.

In this study we analyzed four options for dam construction (Table 1). That the I, II and III axes are respectively from downstream to upstream and the IV axis is between I and II axes. Figures 2-5 show the options situation. We selected the IV axis as dam site and center of study area. Dam site and its abutments are located on igneous rocks.

Seismotectonic Setting and Historical Seismicity

The Alburz region is characterized by left lateral strike slip and reverse earthquakes mechanism. The data necessary for the seismic hazard analysis were obtained from a survey of the type, location and characteristics of seismic sources, especially faults. Information obtained from earthquake catalogues gave input on the historical seismicity of the region. The catalogues were also used as a basis for probabilistic analyses of earthquake ground motions. The area surveyed for assessing the seismicity comprised a circle with a radius of about 100 km from the site. Epicenters in this region are shown in Figure 6.

Most of the major faults in the dam area follow an NE-SW trend. The Mazandaran and Aliabad Faults were identified as major active faults. The strongest historical earthquake relevant to the Ghomes area is the event of 856 with an estimated magnitude Ms 7.4. This event can be ascribed to the activity of the Astaneh fault or Damghan fault.

Estimation of Peak Ground Motion Parameters

Seismicity Parameters

The estimation of the seismicity parameters (Mmax and recurrence relationships) was performed by making use of both the classical approach of Gutenberg & Richter and of the Kijko-Sellevoll method, which uses a doubly truncated Gutenberg-Richter equation (Kijko & Sellevoll, 1992; Kijko & Graham, 1998). The latter has the advantage of accepting mixed data of two types, one containing only the largest earthquakes and the other containing data sets which are complete from different thresholds of magnitude upwards. The method can also consider gaps when records in the catalogue are missing and uncertainties in earthquake magnitudes.

Attenuation Relationships

Seismic loads imposed on a dam structure by ground motions are usually expressed as peak values of ground acceleration, velocity, and displacement. The peak ground acceleration (PGA) is then often used to quantify the seismic hazard for a structure. The values of PGA and other ground motion parameters at a site are estimated by so-called attenuation laws which in their simplest form are expressed as:

Log Y (ground motion parameter) = log f1 (magnitude) + log f2 (distance) +…+ ε

Attenuation of ground motion depends on many factors such as the fault mechanism, site geological conditions, thickness and type of overburden, etc. The most recent attenuation laws have also taken into account these effects. For this study the relationships of Boore & Joyner (1997), Ambraseys & Douglas (2003) and Campbell & Bozorgnia (2003) were used.

Probabilistic Seismic Hazard Analysis (PSHA)

PSHA allows the use of multi-valued or continuous events and models to arrive at the required description of the earthquake hazard. Ground motion levels are expressed in terms of probabilistic estimates such as the probability of the PGA for a given period of time. The method also allows quantifying the uncertainty of the ground motion parameters. Two models were considered, namely (i) the seismic point source model and (ii) the seismic line source model.

Seismic Point Source (or Poisson) Model

This is the oldest approach employing probabilistic tools. The earthquakes are modeled as point sources considering magnitude, epicenter and focal depth. Events are considered independent of each other. The use of this model is advantageous for situations where the identification of faults in an area is difficult and where large and frequent earthquakes have occurred near the site. However, the method cannot consider uncertainties in magnitude and epicentral distance nor does it accept historical earthquakes in the calculations. Since there are numerous large historical earthquakes around the Mohammadabad dam site, results obtained by this model are believed not to be reliable and they are used for reference purpose only. Calculations were performed using the Gumbel type I distribution function.

Seismic Line Source Model

This model better fits the many line sources (faults). It can be treated by the well-known software SEISRISK III (Bender & Perkins, 1987). Input parameters required include: geometry and location of each seismic source (fault, source zones, including uncertainty), attenuation relationships, and seismicity parameters β and λ (used in the 5 distribution function of the doubly truncated Gutenberg-Richter equation). The main output obtained from this program is the probability of a ground motion parameter (PGA or spectral acceleration) not being exceeded during a fixed period of time at the site.

For estimating the seismic potential (maximum magnitude) of a fault the Wells & Coppersmith (1994) relationship was used which is based on worldwide data and also fits well with data from Iran. Calculations were carried out for return periods between 500 and 1000 years. In order to obtain a weighted average of the results calculated with the three attenuation laws, a logic tree approach with three branches was applied. Selected results are shown in Table 2 in terms of the median + one standard deviation (84th percentile). The values obtained from the line source model were considerably higher than those derived from the point source model.

Deterministic Seismic Hazard Analysis (DSHA)

The purpose of the DSHA is to find the worst possible scenario among all the possible seismic sources related to the studied site. The analysis comprises four steps: (1) Identification of the active faults closest to the site, (2) determining the maximum earthquake that could be generated by these faults, (3) selection of appropriate attenuation laws, and (4) determination of the hazard at the site. The maximum values of PGA were calculated for twelve faults or fault segments affecting the dam site using the same attenuation laws as for the PSHA. The distance to the seismic source was taken as the closest distance to the vertical projection of the rupture for the Ambraseys & Douglas and Boore & Joyner attenuation laws and as the closest distance to the seismogenic rupture surface in case of the Campbell & Bozorgnia law. A weighted average was calculated using a logic tree approach. The results are given in Table 3.

Ground Motion Design Levels

Four ground motion levels were considered to define the seismic design requirements for the dam and appurtenant structures. These design levels are partly defined by ICOLD (1989) and partly follow Iranian design practice for dam structures (ICSRDB, 1999). The basic idea is to allow for certain damages during an earthquake of a relatively long return period compared to the lifetime of the structure but not to endanger people's life. The four ground motion levels are defined in following on.

Design Basis Level (DBL)

Ground motions of this level are expected to occur during the lifetime of the dam. Some minor damage to structures and equipment is accepted but they must remain functional. A PSHA is the most suitable method to establish this level and a return period of between 150 and 500 years is assumed (usually 475 years).

Maximum Design Level (MDL)

This level of ground motions has a low probability of occurrence with a return period of between 1000 and 5000 years. The dam and appurtenant structures shall be able to resist these ground motions but larger damages are accepted. Safety related devices, such as spillway gates, must remain operational. PSHA is most appropriate to establish values for this ground motion level.

Maximum Credible Design Level (MCL)

This level is defined as the largest ground motion that can reasonably be expected at the site from a nearby seismic source or on the basis of the seismic history and tectonics of the region. The DSHA is considered the most appropriate approach to estimate ground motion levels for this scenario. The dam and appurtenant structures may sustain irreparable damage but the uncontrolled release of reservoir water must be prevented.

For Mohammadabad dam site, return periods of 500 and 1000 years were considered for the DBL and MDL respectively and using the 84th percentile of the distribution, while for the MCL the Aliabad fault with the 50th percentile was taken. The resulting PGA values are summarized in Table 4.

Estimation of Response Spectra

For design and analysis of structures a convenient way to express ground motions is the response spectrum which gives the maximum response (acceleration, velocity, or displacement) of a simple oscillator to the ground motion. The oscillator has the same period of vibration as the fundamental period of the structure. The maximum response is plotted versus the undamped natural period or the natural frequency. Site-specific response spectra are derived from ground motions arising from distinct, well-identified seismic sources in the region considered.

For Mohammadabad dam site different methods were chosen to calculate the specific response spectra, namely: (1) probabilistic method using the line source model and (2) deterministic method using active faults in the site area. In the following these two methods are briefly described.

Response Spectra from Line Source Model

Some of the attenuation laws used in the PSHA are also frequency dependent. These laws were used to establish so-called Uniform Hazard Spectra or Equal Probability Spectra. On such a spectrum curve each point has an equal probability of exceeding a ground motion parameter (acceleration, velocity, displacement). By means of the logic tree procedure weighted averages of the spectra can be derived. Figures 7-10 show the acceleration response spectra with different return periods from such scaled accelerograms for both the horizontal and the vertical component.

Response Spectra from Deterministic Model

This model is used for the estimation of the response spectrum for the MCL. The ground motions at a site are estimated deterministically for a selected earthquake scenario. After having determined the earthquake magnitude of a specific seismic source and the closest distance to the site, the site ground motions are estimated using ground motion attenuation laws. The response spectrum is then calculated within a certain range of periods. 50th and 84th percentile values can then also be computed for different damping values (Figures 11-12).

CONCLUSION

The seismic hazard at the Mohammadabad dam sites has been estimated by means of probabilistic and Deterministic methods to obtain the ground motion levels for the design of the dam and appurtenant structures. The dams and relevant structures are designed for the median (50th percentile) of the maximum credible level (MCL). This yields peak ground acceleration of 0.42 g in the horizontal and of 0.32 g in the vertical direction. Response spectra were produced for the design of concrete structures and acceleration-time histories, compatible with the design site-specific response spectrum, for the design of the dams and slopes. The study Seismotectonic region has experienced numerous large historical and 20th/21st century earthquakes with Ms between 0.4-7.4. The recent M 6.9 event demonstrates, however, that earthquakes are possible anywhere in the region. Often earthquakes in this region cannot be related to a mapped surface fault and they occur in between the branches of the major faults. The Aliabad fault was considered as the most dominant structure in the deterministic analysis. Smaller faults around the sites are considered non-active or of lower seismic potential. Considering that events of surface faulting may be separated by quiescent periods of 3000 to 5000 years (Berberian & Yeats, 1999), the choice of more conservative ground motion values derived from the Aliabad fault is justified.

REFERENCES

Ambraseys, N.N. & Douglas, J. (2003), "Near-field horizontal and vertical earthquake ground Motions", Soil Dynamics and Earthquake Engineering, Vol.23, pp.1-18.

Bender, B. & Perkins, D.M. (1987), "SEISRISK III, a computer program for seismic hazard Estimation", US Geological Survey, Bulletin 1772.

Boore, D. M., W. B. Joyner and T. E. Fumal, 1997. " Equations for Estimating Horizontal Response Spectra and Peak Acceleration from Western North American Earthquakes", A Summary of Recent Work, Seism. Res. Lett. Vol. 68, No. 1, pp. 128-153.

Campbell, K.W. & Bozorgnia, Y. (2003), "Updated near-source ground motion (attenuation) relations for the horizontal and vertical components of peak ground acceleration and acceleration Response spectra", Bulletin of the Seismological Society of America, Vol.93, No.1, pp.314-331.

ICOLD (1989), "Selecting Seismic Parameters for Large Dams, Guidelines", Bulletin 72, International Commission on Large Dams, Paris.

ICSRDB, 1988. "Iranian Code for Seismic Resistant Design of Buildings", Publication No. 20, Building and Housing Research Center, Ministry of Housing and Urban Development, Islamic Republic of Iran.

Kijko, A. and Sellevoll, M. A., 1992. "Estimation of Earthquake Hazard Parameters from Incomplete Data Files. Part II. Incorporation of Magnitude Heterogeneity", Bulletin of the Seismological Society of America, Vol. 82, No. 1, pp. 120-134.

Kijko, A. & Graham, G. (1998), "Parametric-historic procedure for probabilistic seismic hazard Analysis, Part I: Assessment of maximum regional magnitude Mmax", Pure and Applied Geophysics, Vol.152, pp. 413-420.

Wells, D.L. & Coppersmith, K.J. (1994), "New empirical relationships among magnitude, rupture Length, rupture width, rupture area and surface displacement", Bulletin of the Seismological Society of America, Vol.84, No.4, pp.974-1002.

LIST OF TABLE TITLES AND FIGURE CAPTIONS

TABLES WITH TITLES

Table 1 . Dam options coordinates.

Axis	Long.	Lat.
I	54.782	36.844
II	54.813	36.817
III	54.817	36.796
IV	54.791	36.832

TABLES WITH TITLES

Table 2 . Values of PGA obtained from PSHA using line source model

Return Period (year)	**Peak ground acceleration (g)**	
	horizontal	**vertical**
	84th percentile	**84th percentile**
500	0.35	0.24
1000	0.41	0.29

TABLES WITH TITLES

Table 3. Values of PGA obtained from DSHA (in fractions of g)

Fault name	Distance (km)				Ms	Power plant site			
						horizontal		vertical	
	I	II	III	IV		50%	84%	50%	84%
Mazandaran	5.5	9	11.5	7.2	7.2	0.40	0.63	0.26	0.45
Aliabad	3.5	0	2.5	2	6.8	0.42	0.66	0.32	0.54

TABLES WITH TITLES

Table 4. Values of PGA for different design levels

Design level	Return period (year)	Power plant site Peak ground acceleration (g)	
		horizontal	vertical
DBL (84th percentile)	500	0.35	0.34
MDL (84th percentile)	1000	0.41	0.29
MCL (50th percentile)	Deterministic	0.42	0.32

FIGURES WITH CAPTIONS

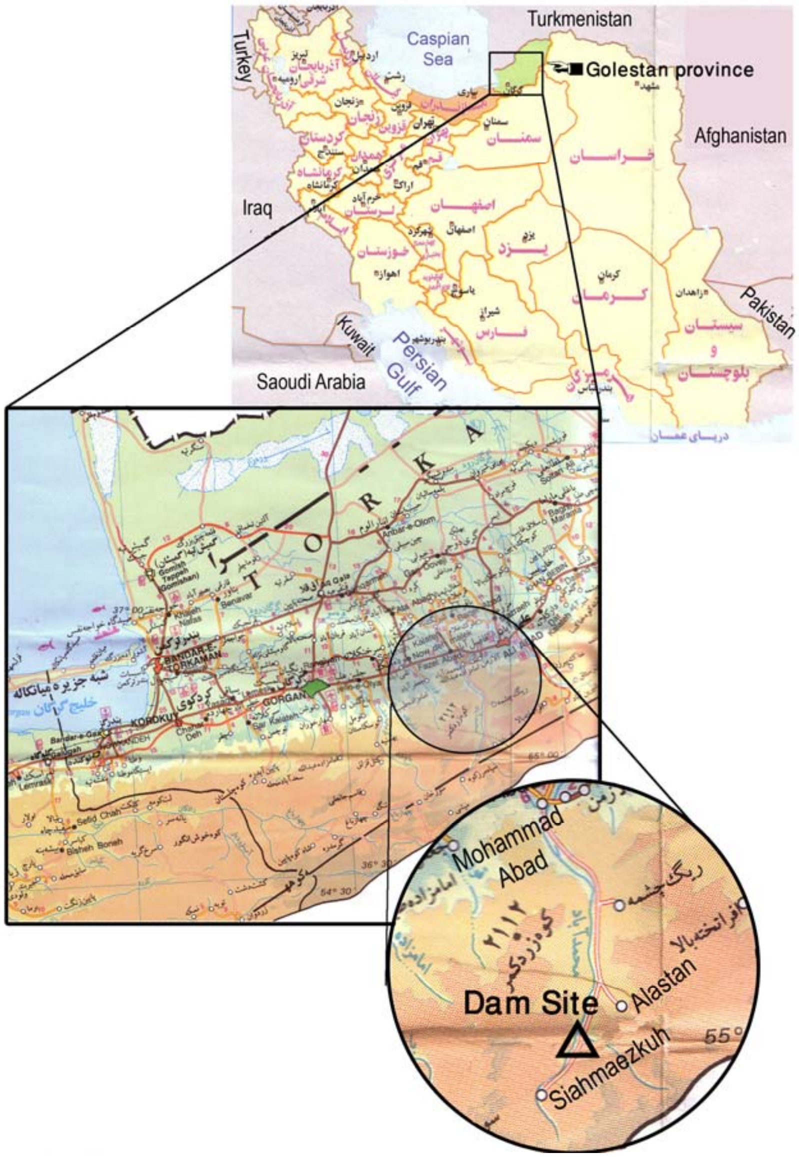

Figure 1. Location of the Mohammadabad dam site in the north of Iran.

FIGURES WITH CAPTIONS

Figure 2. Location of the I axis.

FIGURES WITH CAPTIONS

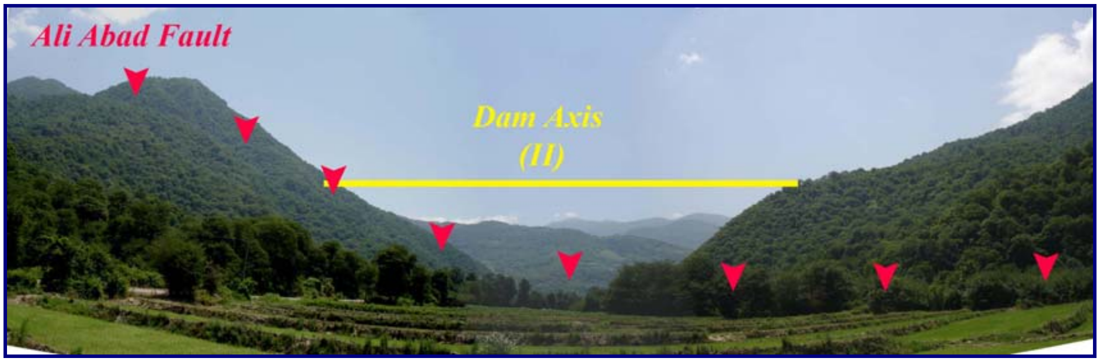

Figure 3. Location of the II axis.

Figure 4. Location of the III axis.

FIGURES WITH CAPTIONS

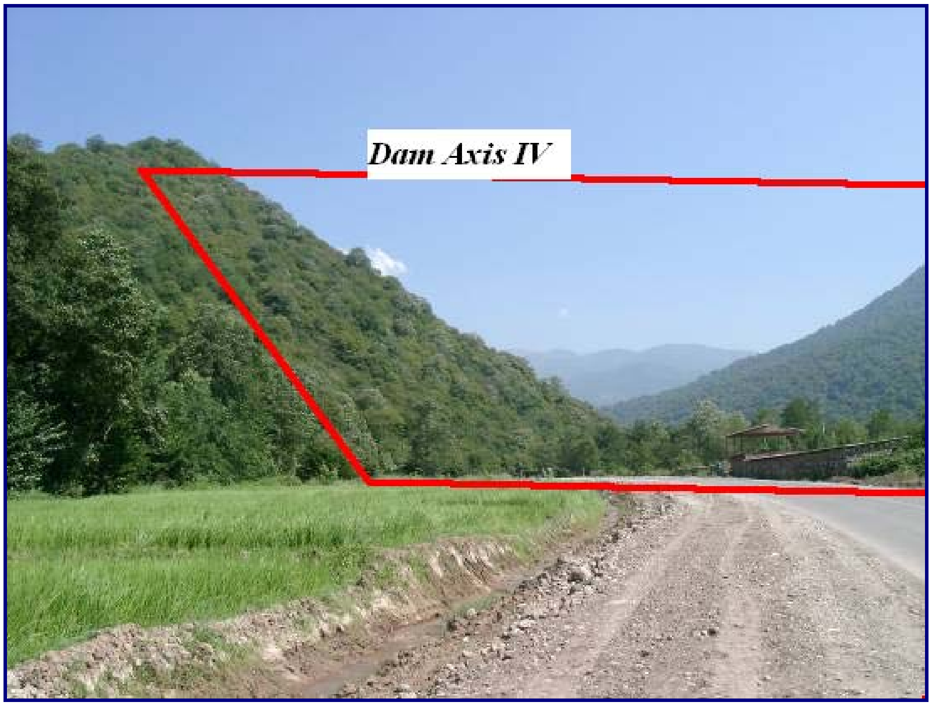

Figure 5. Location of the IV axis.

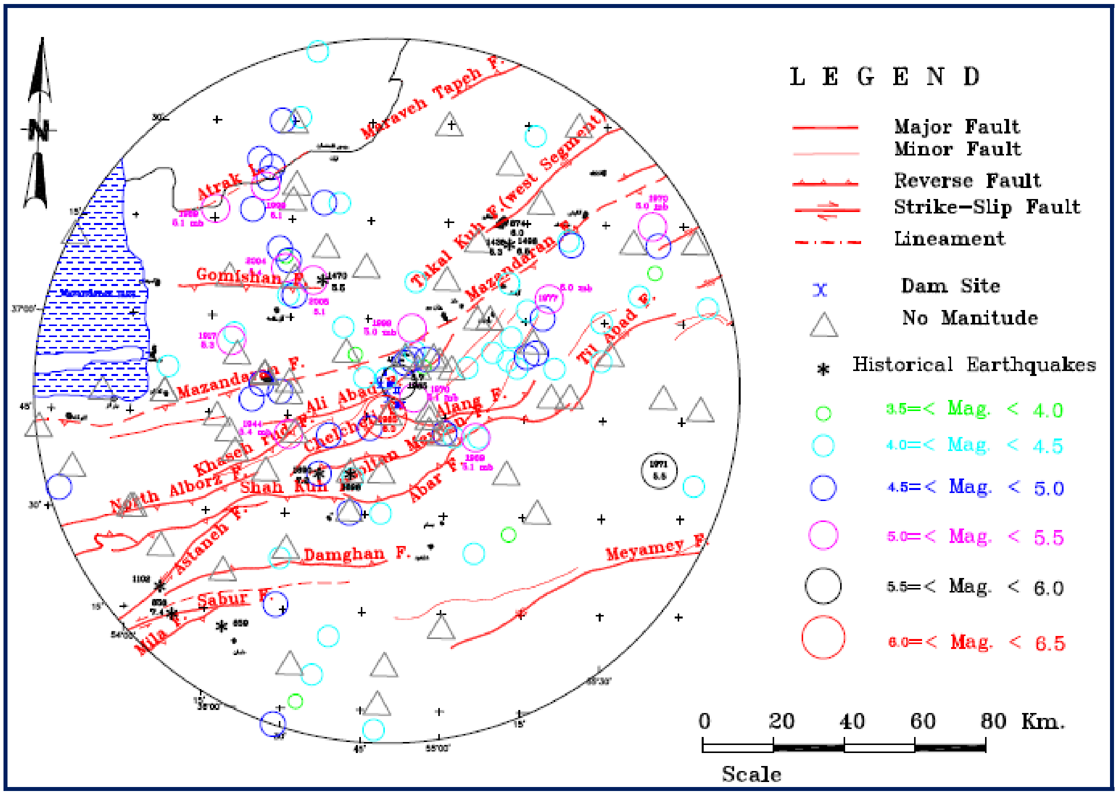

Figure 6. Location of earthquake epicenters within a radius of 100 km around the site

FIGURES WITH CAPTIONS

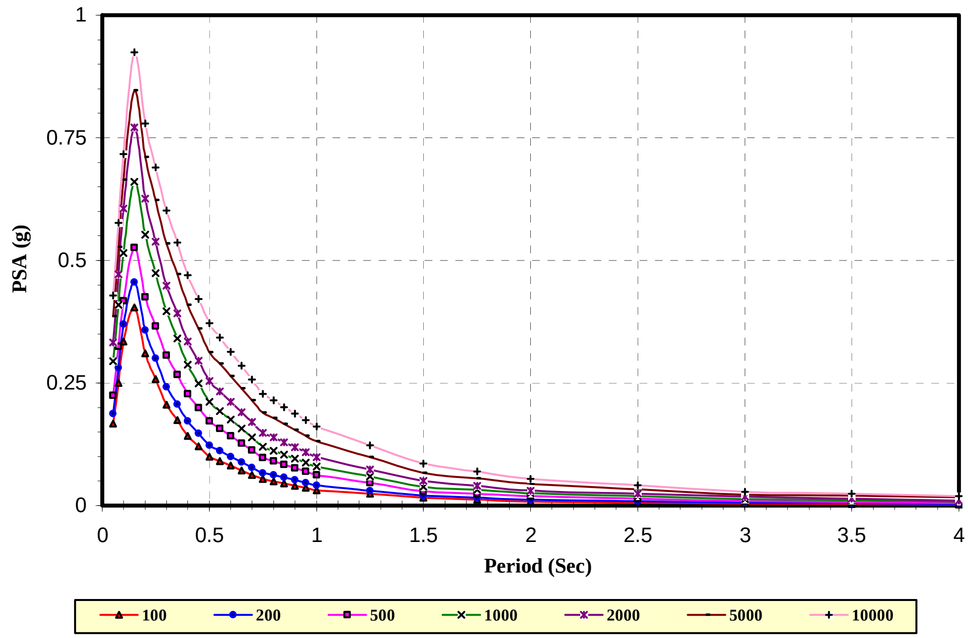

Figure 7. Acceleration response spectra based on probabilistic processing for different periods and the horizontal component for the 50th percentile level.

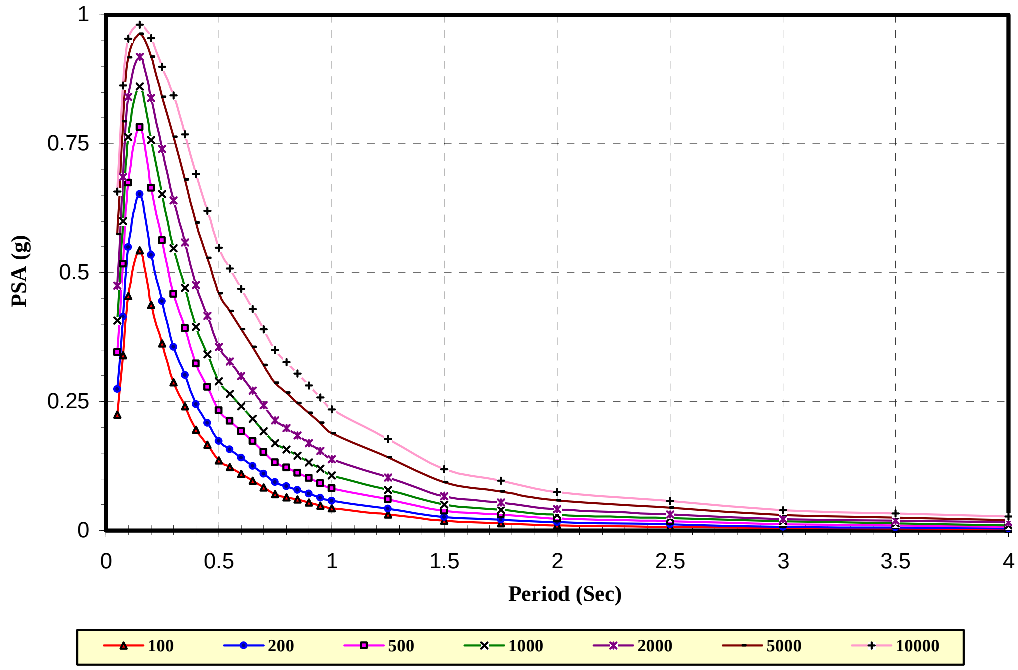

Figure 8. Acceleration response spectra based on probabilistic processing for different periods and the horizontal component for the 84th percentile level.

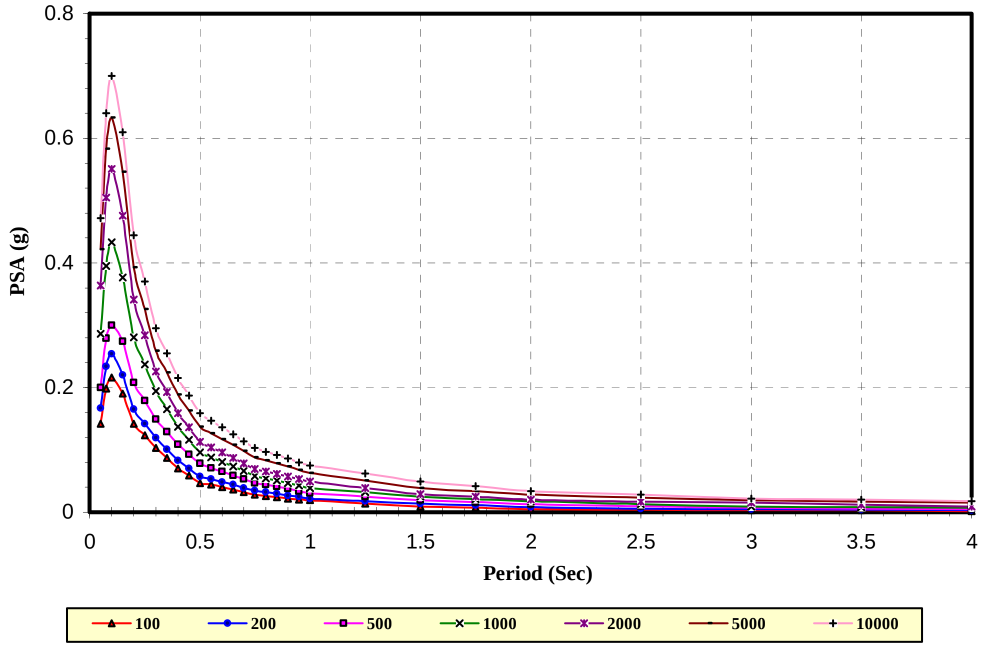

Figure 9. Acceleration response spectra based on probabilistic processing for different periods and the vertical component for the 50th percentile level.

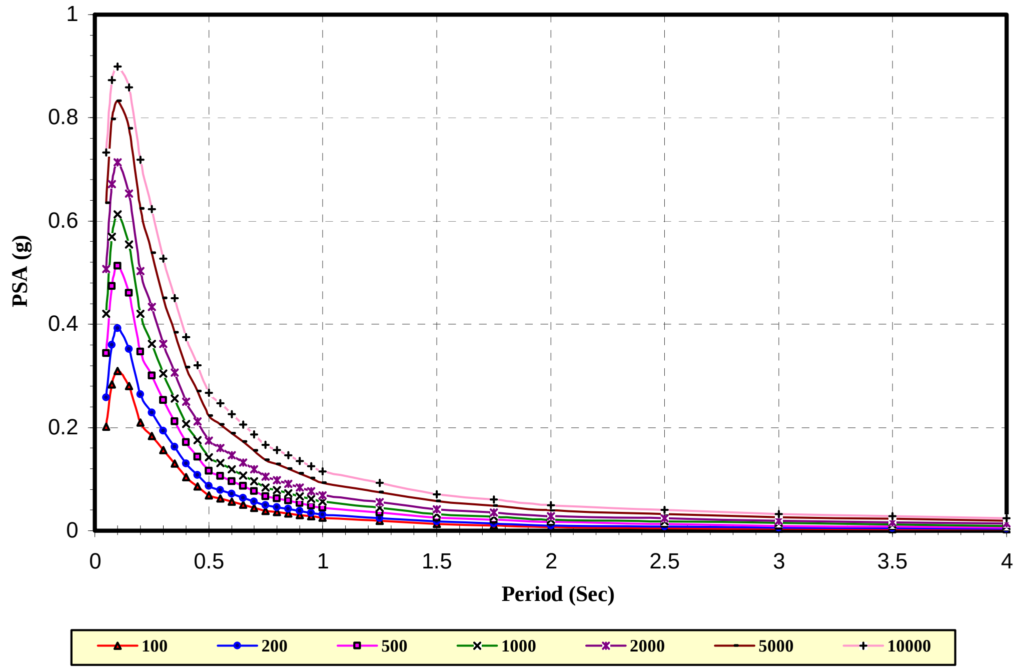

Figure 10. Acceleration response spectra based on probabilistic processing for different periods and the vertical component for the 84th percentile level.

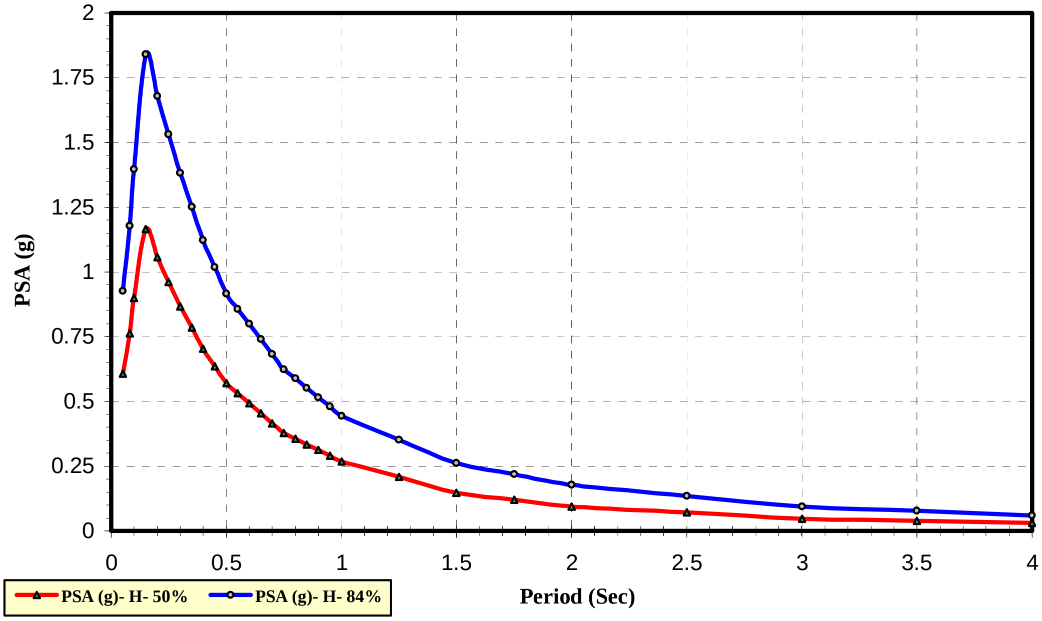

Figure 11. Acceleration response spectra based on deterministic processing for the horizontal component for the 50th and 84th percentile level.

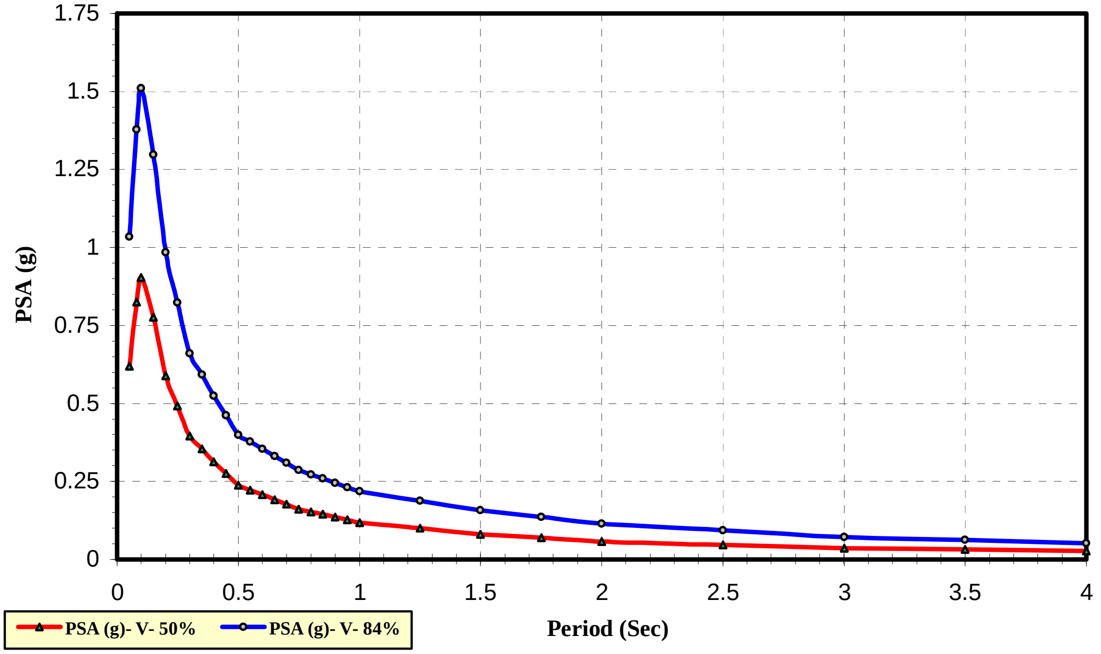

Figure 12. Acceleration response spectra based on deterministic processing for the vertical component for the 50th and 84th percentile level.