Seismic Hazard Analysis for Sungun High Centerline Tailings Dam

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Abstract

Sungun high centerline tailings damis located near Varzaghan city, Iran on the Zarnekab River 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), Design Basis Level (DBL) and Operation Basis Level (OBL) 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 were assessed based on topographic, geologic and aeromagnetic maps, air photos, field investigation, and a comprehensive search in the literature. Results are been presented in terms of peak ground acceleration (PGA) and acceleration response spectra.

Keywords: Seismic Hazard Analysis, Response Spectra, PGA, Tailings Dam, Iran.

1. INTRODUCTION

Sungun porphyry copper mine is located 125 km northeast of Tabriz, in north-western Iran (43° 46′ E and 38° 42′ N) (Fig. 1). This project falls within a region of high seismicity, in the Azerbaijan seismotectonic province (a part of central Iran seismotectonic region). To estimate the ground motion parameters, a comprehensive seismic hazard analysis has been 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, which then described together with selected results.

2. SEISMOTECTONIC SETTING AND HISTORICAL SEISMICITY

The central Iran seismotectonic region is characterized by the earthquakes which distinguish az high magnitude, long period and few numbers of occurrences.

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 (Fig. 2).

Most of the major faults in the study area follow an NNE-SSW trend. The Musakandi Fault was identified as a major active fault. The strongest historical earthquake relevant to the Tabriz city of northwest Iran is the event of 1780 with an estimated magnitude Ms 7.4. This event can be ascribed to the activity of the Tabriz north fault.

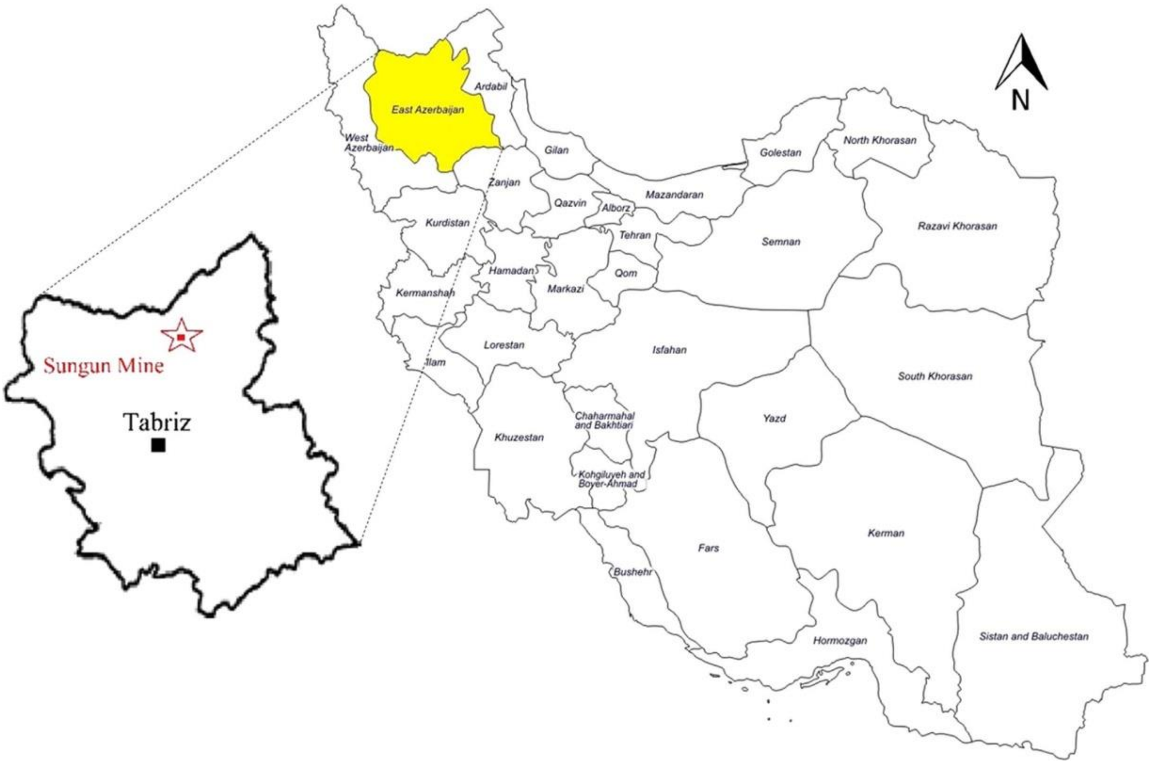

Figure 1. Location of Sungun copper mine in Iran.

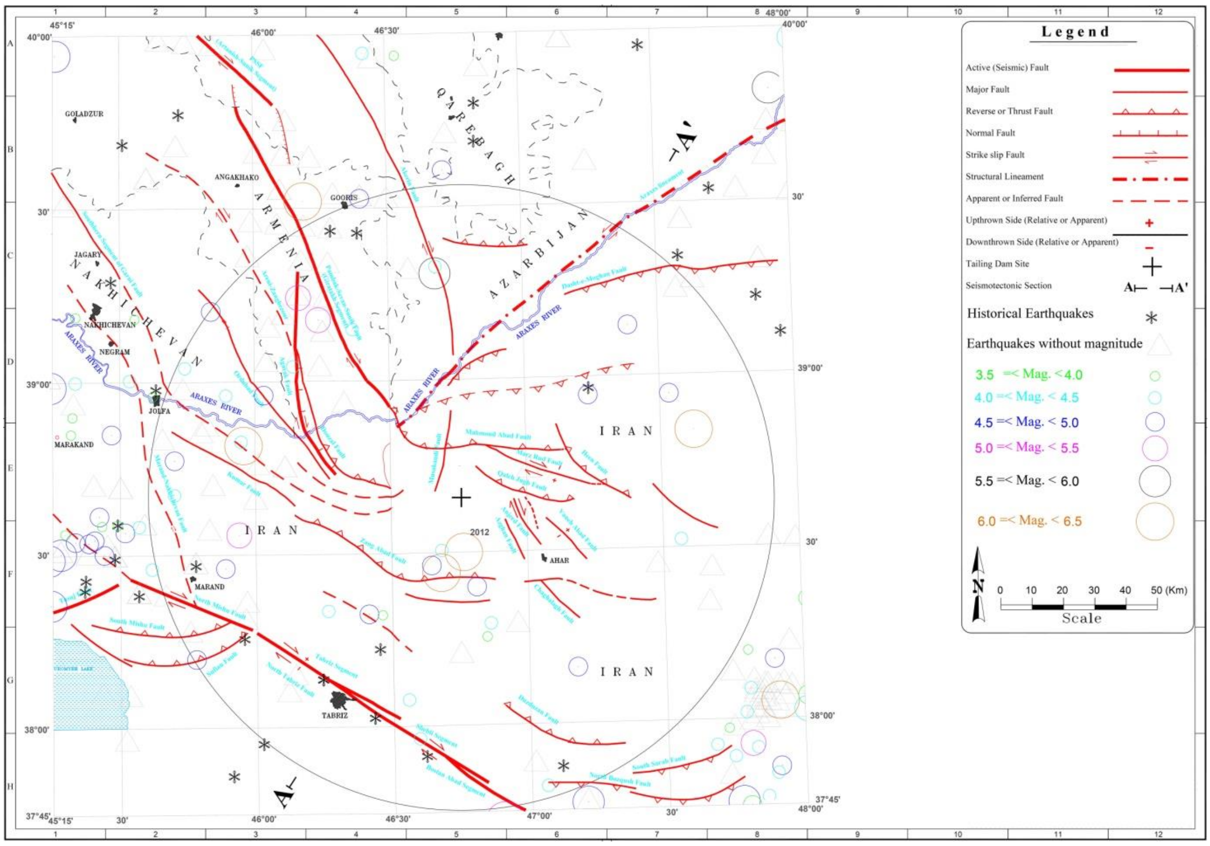

Figure 2.Location of earthquake epicenters within a radius of 100 km around the site

3. ESTIMATION OF PEAK GROUND MOTION PARAMETERS

3.1. SEISMICITY PARAMETERS

The estimation of the maximum magnitude (Mmax) and recurrence relationships was performed using by both of the classical approaches of Gutenberg & Richter [1] and the Kijko-Sellevoll method [2].

The advantages of using both of these methods are containing the largest earthquakes and 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.

3.2. ATTENUATION RELATIONSHIPS

Seismic loads imposed on a dam structure such as power plant by ground motions are usually expressed as peak values of ground acceleration, velocity, and displacement. The peak ground acceleration (PGA) is often used to quantify the seismic hazard for a structure. The values of ground motion parameters (Y) at a site (Include PGA) are estimated by so-called attenuation laws which in their simplest form are expressed as "Eq. (1) ".

$$\log Y = \log f1\ (\text{magnitude}) + \log f2\ (\text{distance}) + .. + \varepsilon \qquad (1)$$

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 Campbell [3], Ambraseyset al. [4], Booreand Atkinson [5] and Ghodrati et al. [6] were used.

3.3. GROUND MOTION DESIGN LEVELS

Four ground motion levels were considered to define the seismic design requirements for the tailings dam and appurtenant structures. These design levels are partly defined by the International Committee of Large Dams [7] and Building and Housing Research Center of Iran [8]. 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.

3.3.1. OPERATING BASIS LEVEL (OBL)

The Operating Basis earthquake is expected to occur during the lifetime of the dam. The OBE represents the level of ground motion at the dam site which no damage is acceptable. In this study recommended return period of occurring of the OBE is about 150 years.

3.3.2. DESIGN BASIS LEVEL (DBL)

Ground motions of this level are expected to occur during the lifetime of the power plant. 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 is about 500 years (usually 475 years).

3.3.3. MAXIMUM DESIGN LEVEL (MDL)

This level of ground motions has a low probability ofoccurrence with a return period of about 2475 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.

3.3.4. 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 based on 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. In this study Return Period of occurring of the MCE is more than 2500 years.

For Sungun tailings dam, return periods of 150, 500 and 2500 years were considered for the OBL, DBL and MDL respectively and using the 84th percentile of the distribution.

3.4.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 occurrence of the PGA for a given period time. The method also allows quantifying the uncertainty of the ground motion parameters. Two models were considered, the seismic point source model and the seismic line source model.

3.4.1. 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 the magnitude and epicentral distance nor does it accept historical earthquakes in the calculations. Since there are numerous large historical earthquakes around the Sungun tailings 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 [9].

3.4.2. SEISMIC LINE SOURCE MODEL

This model better fits the many line sources (faults). It can be treated by the well-known software SEISRISK III [10]. 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 [1]). The main output obtained from this program is the probability of a ground motion parameter (PGA or spectral acceleration) not is exceeded during a fixed period time at the site.

For estimating the seismic potential (maximum magnitude) of a fault the Wells & Coppersmith relationship was used which is based on worldwide data [11]. Calculations were carried out for return periods between 100 and 2500 years. 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 1). The values obtained from the line source model were considerably higher than those derived from the point source model.

Table 1- Values of PGA obtained from PSHA using line source model

Design level	Return period (year)	Dam site	
		Peak ground acceleration (g)	
		horizontal	vertical
OBL (84th percentile)	200	0.18	0.15
DBL (84th percentile)	500	0.26	0.22
MDL (84th percentile)	2500	0.39	0.33
MCL (84th percentile)	Deterministic	0.51	0.45

3.5.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 Campbell [3], Ambraseyset al. [4], Boore and Atkinson [5] and Ghodrati et al. [6] laws. A weighted average was calculated using a logic tree approach. The results are given in (Table 2).

Table 2- Values of PGA obtained from DSHA (in fractions of g)

Fault name	Distance (km)	Ms (Richter)	PGA (g)			
			horizontal		vertical	
			50%	84%	50%	84%
Musakandi	8	6.5	0.31	0.53	0.21	0.37

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 Sungun high centerline tailings dam, different methods were chosen to calculate the specific response spectra, namely: (1) probabilistic method using the line source model, (2) deterministic method using active faults in the site area, and (3) statistical method using existing strong motion records. In the following, these three methods are briefly described.

4.1.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). Using the logic tree procedure, weighted averages of the spectra can be derived.

4.2.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.

4.3.RESPONSE SPECTRA FROM STATISTICAL ANALYSIS

In this method, originally proposed by Kimball [12], a suite of strong motion records is statistically treated. These records should originate from earthquakes with similar distances to the rupture source and the magnitude should be of the same order as the target magnitude. Some corrections for differences in site conditions may also be needed. The steps are as follows:

- Selection of suitable strong motion records having magnitudes and distances to the source similar to the target parameters of the earthquake.

- Adjustment of the records for differences in magnitude, distance, faulting mechanism, and other parameters between site-specific conditions and the conditions existing at the site of the record
- Performing a statistical analysis of the adjusted response spectra of the collected records to obtain the target values of the site-specific spectrum. The median (50th percentile) and the median plus one standard deviation (84 percentile) are then selected as DBL and MDL levels respectively. For Sungun high centerline tailings dam sites, site-specific ground motions for distance ranges (about 30 km) similar to the target magnitude were calculated and statistically analyzed. (Fig. 3 and 4) show the horizontal and vertical design response spectra recommended for OBE, DBE, MDE and MCE for this project.

(Fig. 5 and 6) show a comparison between Horizontal components of response spectra estimated by statistical and probabilistic methods together for horizontal and vertical component respectively. The amplitudes of recommended OBE, DBE and MDE response spectra estimated by the statistical method are well coordinated with 150, 500 and 2500 year response spectra estimated by probabilistic method respectively.

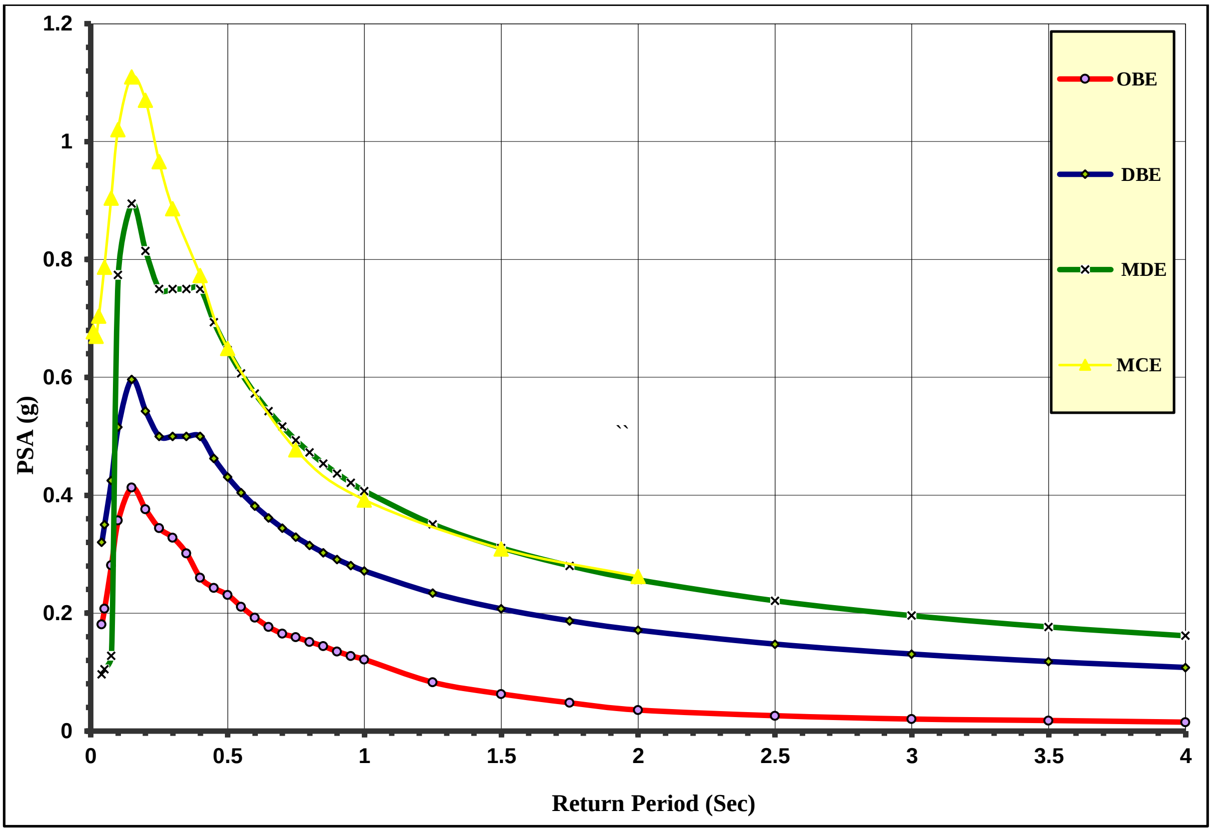

Figure 3.Response spectra based on statistical processing for horizontal component

5. CONCLUSION

The seismic hazard at the Sungun high centerline tailings dam has been estimated using the 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 (84th percentile) of the maximum credible level (MCL). These yields peak ground acceleration of 0.53 g in the horizontal and of 0.37 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 area has experienced numerous large historical and 20th/21st-century earthquakes with Ms between 0.4-7.4. Often earthquakes in this region cannot be related to a mapped surface faulting and they occur between the branches of the major faults. The Musakandi fault was considered as the most dominant structure in the deterministic analysis. Smaller faults around the sites are considered non-active or with low seismic potential. Considering that events of surface faulting may be separated by quiescent periods of 3000 to 5000 years, the choice of more conservative ground motion values derived from the Musakandi fault is justified.

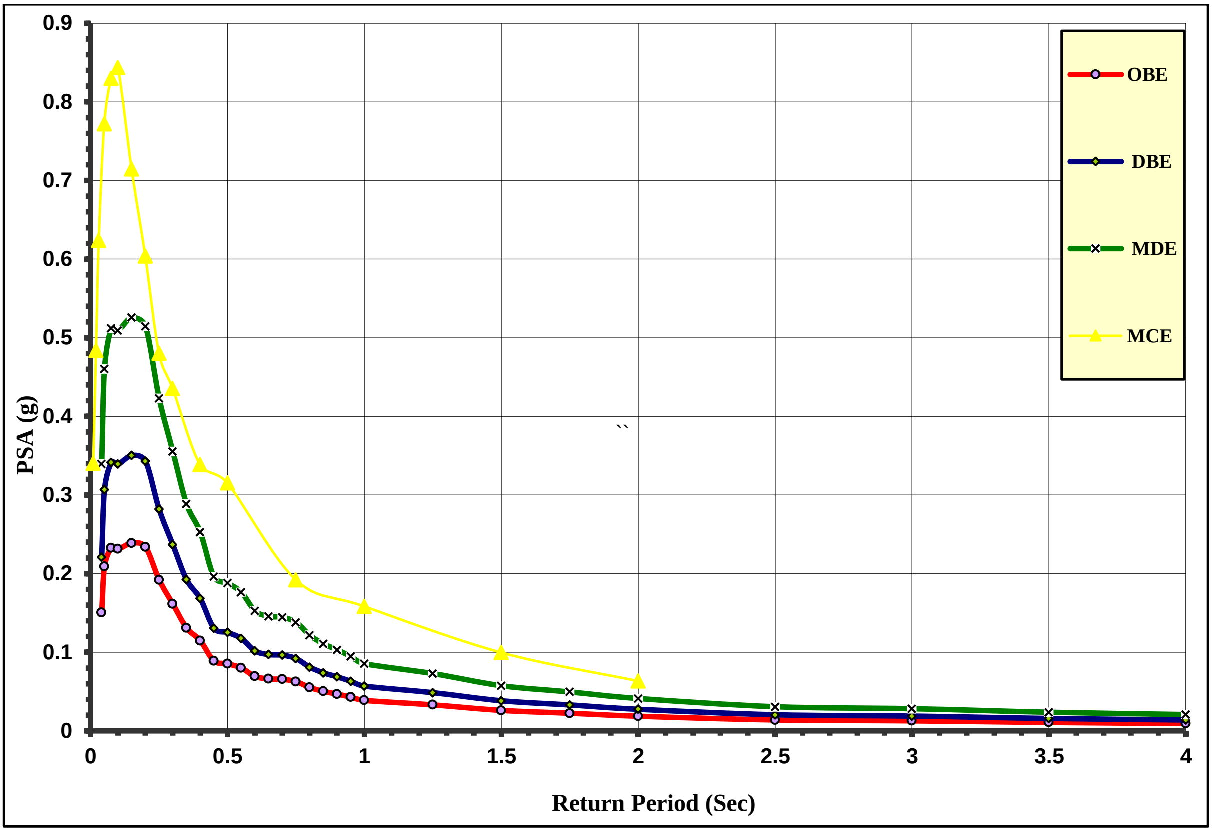

Figure 4.Response spectra based on statistical processing for vertical component

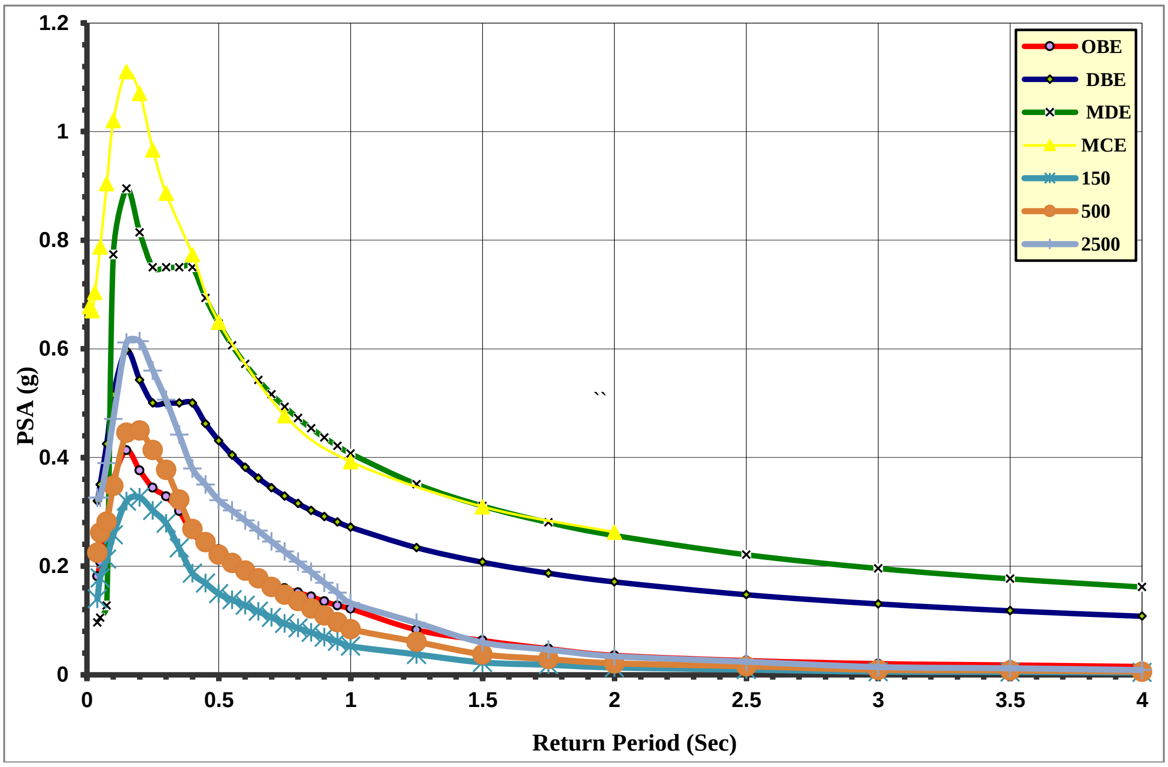

Figure 5. Comparison between response spectra based on statistical & probabilistic processing for different periods & for horizontal component

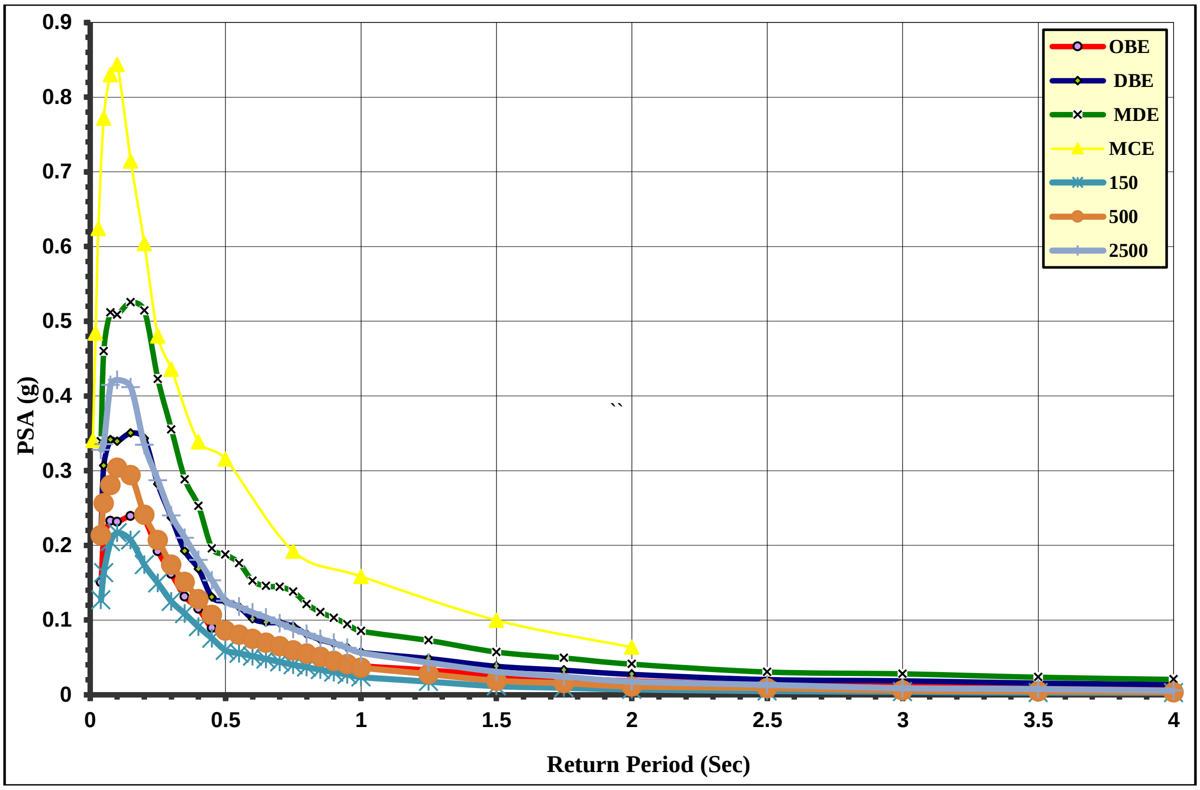

Figure 6.Comparison between response spectra based on statistical & probabilistic processing for different periods&for vertical component

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