SEISMIC HAZARD ANALYSIS FOR MIRABAD PUMPED-STORAGE PROJECT

S. SOLEYMANI[1], M.DALIRI [1], A.ADIB[2], H.BAHRAMI[2]

1- Expert of Dam Constructing Group, Toossab Consulting Engineers Co., Iran

2- Expert of Technical Office in Khorasan Razavi R.W.O, Iran Ministry of Power

Soleymani29@gmail.com

Abstract

The Mirabad pumped-storage project, now under feasibility study stage and predicted as a lower CFR dam and a upper cut & cover dam, is located in a region of high seismicity. A seismic hazard analysis was performed to determine the design ground motion parameters for the project The ground motion parameters for the MDL, DBL and CL were obtained from a PSHA whereas the MCL ground motion was derived from a DSHA. Among the many faults occurring within the area considered for the analysis, there are four major faults (i.e. Binalud, Neyshabur, North Neyshabur and Fariman), all with a seismic potential of M≥6.9 and a rupture length exceeding 0.5 km, regarded as the most critical ones for the Mirabad dam site. The Binalud fault, a WNW-ESE-striking thrust fault is the one closest to the project site with a distance to the seismogenic rupture surface of only 0.5 km. With this fault the medians (50^{th} percentile) of the PGA for the MCL are respectively: 0.72g and 0.57g for the Lower Dam site.

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

1. INTRODUCTION

The Mirabad dam project, located about 20 km north of Neyshabur and east of Bar river (see Figure 1), predicted as a concrete face rockfill dam (CFRD) of 50 m and a upper cut & cover dam of 40 m height. This project falls within a region of high seismicity, the Koppeh-Dagh seismo-tectonic province. 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 and design accelerograms for different design levels is then described together with selected results.

2. SEISMOTECTONIC SETTING AND HISTORICAL SEISMICITY

The Koppeh-Dagh region is characterized by thick layers with Max thickness 10 km. 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 dam sites. Epicenters in this region are shown in Figure 2.

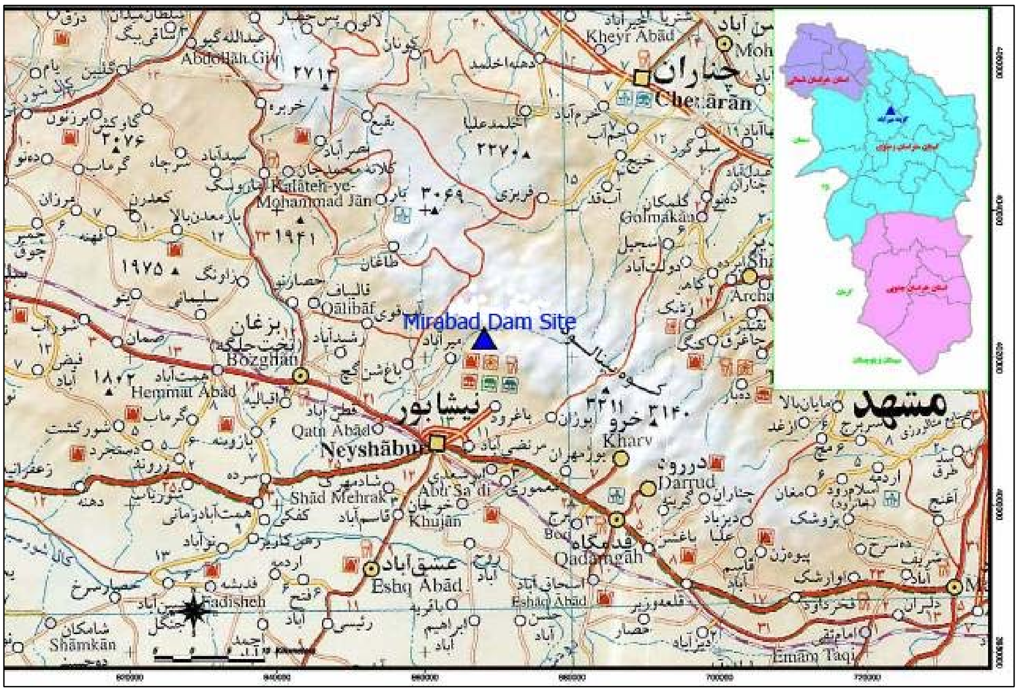

Figure 1. Location of the Mirabad dam site in the north of Iran

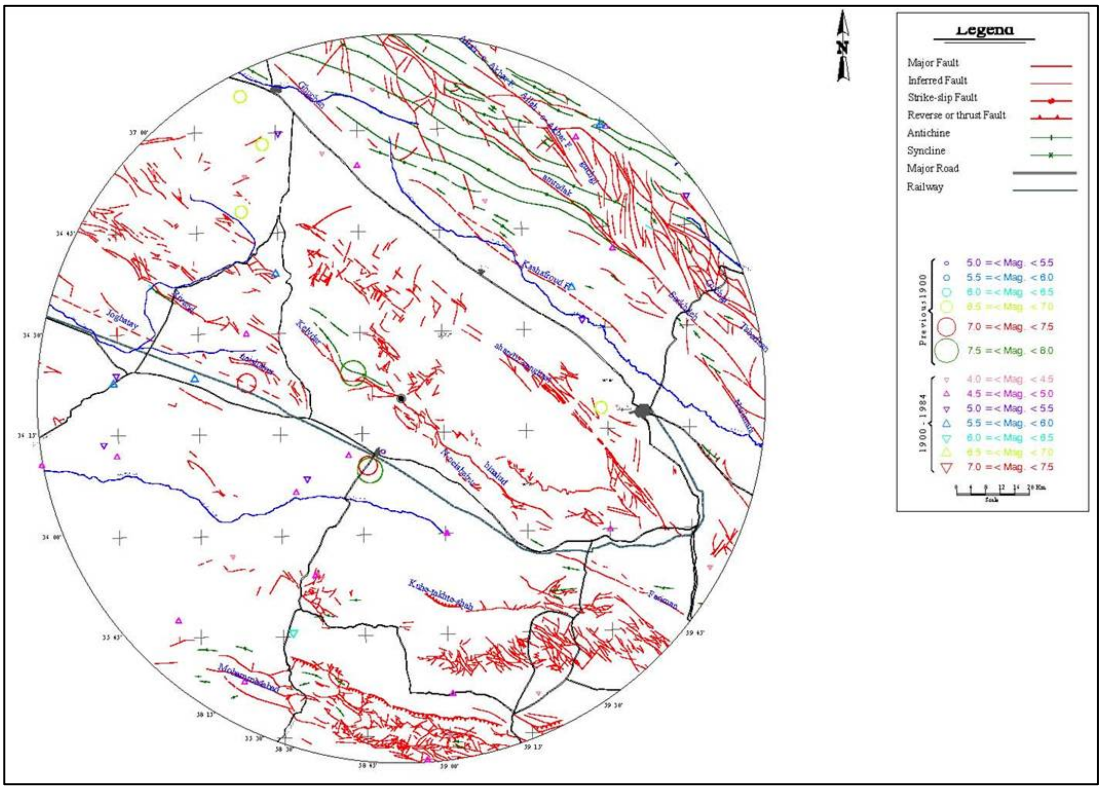

Figure 2. Location of earthquake epicenters within a radius of 100km around the Dam site

The focal depths of the earthquakes in the Koppeh-Dagh mountain range are rather shallow, i.e. less than about 15 km. Most of the major faults in the project area follow an NW to SE trend. Binalud, North Neyshabur, Neyshabur and Fariman Faults were identified as major active faults with a distance to the seismogenic rupture surface less than 10 km.

The review of the historical seismicity showed that within the Koppeh-Dagh seismotectonic province many large earthquakes with magnitudes larger than 6 occurred prior and during the 20th century. the catalogue of earthquakes does not indicate major shocks within a radius of 50 km from the site. The strongest historical earthquake relevant to the Mirabad area is the event of 1405 with an estimated magnitude Ms 7.6 that occurred in the Neyshabur.

3. ESTIMATION OF PEAK GROUND MOTION PARAMETERS

3.1. 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.

3.2. 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 relationships which in their simplest form are expressed as:

$$\log Y(\text{ground motion parameter}) = \log f1(\text{magnitude}) + \log f2(\text{distance}) + \ldots + \varepsilon$$

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 relationships have also taken into account these effects. For this study the relationships of Boore et al. (1997), Ambraseys & Douglas (2003) and Campbell & Bozorgnia (2003) were used. Significant features of these relationships beneficial to this investigation include:

• Use of different accelerograms throughout the world, including those of the Tabas and Manjil earthquake of 1978 and 1990 respectively (both of them in Iran).

• Possibility of calculating maximum values of acceleration and velocity for vertical and horizontal components of the ground motion

• Providing values of pseudo-acceleration response spectra for vertical and horizontal components with 5% damping and periods varying between 0.4 and 4.0 seconds (in Campbell & Bozorgnia), and between 0.1 and 2.0 (in Ambraseys & Douglas)

• Providing models which allow to distinguish between different types of magnitudes (Mw or Ms), source to site distance measurement, different site conditions (hard rock, soft rock, stiff or soft soil), and fault mechanism.

• Possibility to include an error term representing uncertainty in Y arising from the scatter in the attenuation data.

3.3. 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 exceedence of the PGA for a given period of time. The method also allows to quantify 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.

3.3.1. 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 magnitude and epicentral distance nor does it accept historical earthquakes in the calculations. Since there are numerous large historical earthquakes around the Mirabad 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.

3.3.2. Seismic Line Source Model

This model better fits the many line sources (faults) 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 50 and 10,000 years. In order to obtain a weighted average of the results calculated with the three attenuation relationships, a logic tree approach with three branches was applied. The weighting factors assigned to Boore et al (1997), Ambraseys & Douglas (2003) and Campbell & Bozorgnia (2003) were 0.15, 0.15 and 0.70, respectively. Selected results are shown in Table 1 and Figure 3 in terms of the median (50th percentile) and 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.

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

Return Period (years)	Peak ground acceleration (g)			
	Horizontal		Vertical	
	50th percentile	84th percentile	50th percentile	84th percentile
50	0.04	0.12	0.02	0.06
500	0.15	0.30	0.11	0.20
1000	0.20	0.37	0.16	0.25
2000	0.25	0.44	0.20	0.31
10000	0.37	0.62	0.26	0.47

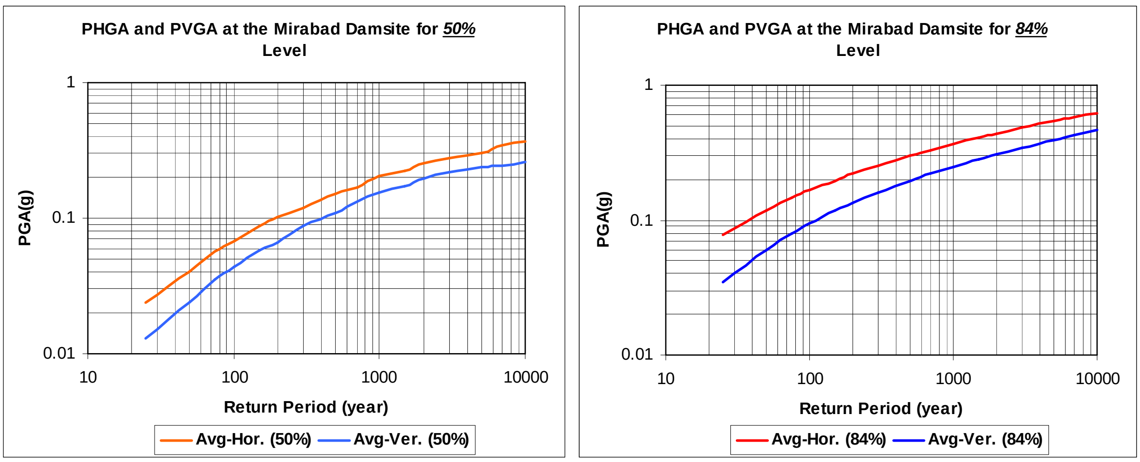

Figure 3. PHGA and PVGA at the Mirabad Dam site

3.4. 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 dam site, (2) determining the maximum earthquake that could be generated by these faults, (3) selection of appropriate attenuation relationships, and (4) determination of the hazard at the site. The maximum values of PGA were calculated for eighteen faults or fault segments affecting the Mirabad dam site using the same attenuation relationships as for the PSHA. The distance to the seismic source was taken as the closest distance to the vertical projection of the rupture for Ambraseys & Douglas and the Boore et al attenuation relationships and as the closest distance to the seismogenic rupture surface in case of the Campell & Bozorgnia law. A weighted average was calculated using a logic tree approach with the same weighting factors as for the PSHA. The results are given in Table 2.

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

Fault Name	Distance (km)	M	PGA		
			Horizontal		Vertical
			50%	84%	50%
Joghatay-Mayamey	15.0	7.4	0.37	0.66	0.24
Ghuchan	39.0	6.7	0.07	0.13	0.03
Rivand	22.0	6.9	0.18	0.33	0.1
Nayshabur	4.3	6.9	0.55	0.8	0.39
Binalud-F1	0.5	7.2	**0.72**	**0.80**	**0.57**
Kashafrud	47.0	6.8	0.06	0.11	0.03
Shandiz-Sangbast	28.0	7.0	0.14	0.25	0.07
Amrudak	71.0	6.8	0.03	0.05	0.01
Sorkhdeh	68.0	6.9	0.03	0.06	0.01
Guchgi	78.0	6.9	0.03	0.05	0.01
North Neyshabur	4.0	7.0	0.6	0.88	0.41
Kelydar	12.0	6.5	0.26	0.47	0.17
Allah-O-Akbar	82.0	6.8	0.03	0.04	0.01
Kuh-E-Takhte Shah	48.0	6.8	0.06	0.11	0.03
Fariman	8.0	7.1	0.47	0.84	0.32
Tabadkan	64.0	6.9	0.04	0.07	0.02
Mohammad abad	88.0	6.5	0.02	0.03	0.007

3.5. 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 as follows:

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.

Construction Level (CL): This level applies during the period of construction. It considers the same hazard as for the DBL but in view of the much shorter time period involved, the return period is reduced to 50 years.

For the Mirabad dam sites, return periods of 500 and 2000 years were considered for the DBL and MDL and the CL known by 80% DBL, respectively and using the 84th percentile of the distribution, while for the MCL the Binalud fault with the 50th percentile was taken. The resulting PGA values are summarized in Table 3.

Table 3. Values of PGA for different design levels

Design Level	Return Period	PGA	
		Horizontal	Vertical
CL (84th percentile)	50	0.24	0.16
DBL (84th percentile)	500	0.30	0.20
MDL (84th percentile)	2000	0.44	0.31
MCL (50th percentile)	Deterministic	0.72	0.57

4. CONCLUSIONS

The seismic hazard at the Mirabad dam site 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 are designed for the median (50th percentile) of the maximum credible level (MCL). This yields a peak ground acceleration of 0.72g in the horizontal and of 0.57g in the vertical direction. The Koppeh-Dagh region has experienced numerous large historical and 20th/21st century earthquakes with M>6.0. However, within a radius of about 100 km around the dam sites there has not been any major event (i.e. M≥7). The recent earthquake observed from the site is Garmkhan-Bojnurd with M 6.7, 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 Binalud fault was considered as the most dominant structure in the deterministic analysis although there are no records of earthquakes along this thrust fault. Smaller faults around the dam sites are considered non-active or of lower seismic potential. The Binalud fault is the closest of the big faults in the region. The more active North Neyshabur fault, with at least four large events attributed to it, has a larger distance from the site with correspondingly more attenuated ground motions. 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 Binalud fault is justified.

5. REFERENCES

Tooss Ab Consulting Engineers Co. (2008), "Feasibility Seismic Studies of Khorasan Province Pumped-Storage Power Plant Projects".

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.

Berberian, M. & Yeats, R.S. (1999), "Patterns of historical earthquake rupture in the Iranian plateau", Bulletin of the Seismological Society of America, Vol.89, No.1, pp.120-139.

Boore, D.M., Joyner, W.B. & Fumal, T.E. (1997), "Equations for estimating horizontal response spectra and peak acceleration from Western North American earthquakes: a summary of recent work", Seismological Research Letters, Vol.68, 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 (1999), Iranian Code of Practice for Seismic Resistant Design of Buildings, Standard no. 2800, 2nd ed., building and Housing Research Center, Publication BHRC PN S 253, Tehran.

Kijko, A. & 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.