Earthquake Safety Evaluation for Dams in Upper Aras Basin, Turkey

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Abstract

The Aras basin, which covers an area of 102,000 km^2, has the Aras river and many tributaries. The Aras river rises from eastern Turkey and drains the south side of the Lesser Caucasus Mountains, then joins the Kura River, which drains the north side of those mountains and joins Caspian sea after 1 072 km. It is a transboundary river, which flows in and along the countries of Turkey, Armenia, Azerbaijan, and Iran. There are so many small and large dams in the basin. However, eighteen of large dams, which are located on Upper Aras basin, were considered for this study. The heights of dams range from 25 to 157 m. The twelve of them are under operation stage while others are under construction and final design stages. Main part of this basin is located on active seismic region. It is clear that earthquake safety of dams is an important aspect in dam engineering and requires more comprehensive seismic studies for understanding the seismic behavior of dams subjected to severe earthquakes. This study evaluates the main concept of seismic hazard analysis and introduces results of analyses executed for dams of Upper Aras basin, Turkey. The analyses indicate that 75 percent of dams pose moderate hazard ratio and two of them are under near source effect when considered the updated seismic data.

Keywords: Earthquake, Aras basin, dam, seismic hazard.

1. INTRODUCTION

Seismic hazard rating of dam site and risk rating of the dam and appurtenant structures are the main factors acting on total risk for dam structures. The seismic hazard of a dam site can be based on the peak ground acceleration. This value derived from the defined design earthquake produces the main seismic loads. For preliminary study, the existing map of seismic zones can be used to estimate the seismic hazard of a dam site. However, the seismic hazard analysis should be performed for safety evaluation of existing dams. The risk rating of the dam can be based on the capacity of the reservoir, the height of the dam, the evacuation requirements and the potential downstream damages. In general, the seismic and risk ratings are evaluated separately [1]. These two factors were combined to define the total risk factor for dam structure [2]. Recently, the guidelines for selecting seismic parameters for large dams have been published by ICOLD [3].

Turkey is a rich country when considered projects in using land and water resources. The total number of large dams constructed throughout all country is over 1200. Most dams are of the embankment type. However, number of concrete dams and rolled compacted concrete dams increases recently. Most of the designers in Turkey believe the fact that embankment dams, which are well compacted according to the specification, are suitable type for regions having high seismic activity. In general, strong ground shaking can result in the instability of the embankment and loss of strength at the foundations. Active faults, which are very close to the foundation of dams, have the potential to cause damaging displacement of the structure. There is a good case in Turkey, which was damaged during the earthquakes, occurred in past [4]. Therefore, earthquake safety is an important concept for dams and their appurtenant structures. This paper deals with an evaluation of seismic hazard and total risk of the large dams, which have a structural height greater than 25 m, in the Upper Aras basin (Figure 1). In the basin, eighteen large dams have been designed to exploit energy and irrigational potential of the basin. Twelve of them are entirely completed.

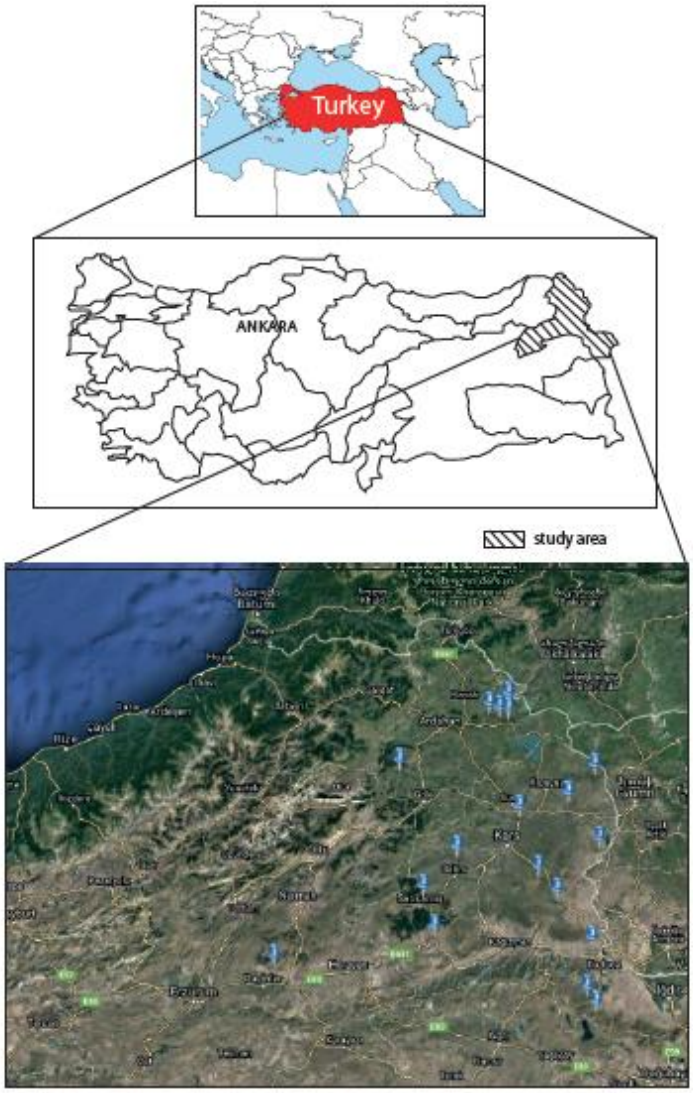

Figure 1. Location of dams considered for this study

2. METHODS OF ANALYSIS

The study of seismic activity is generally performed by means of deterministic and probabilistic seismic hazard analyses. The deterministic seismic hazard analysis considers a seismic scenario that includes a four-step process. It is a very simple procedure and gives rational solutions for large dams because it provides a straightforward framework for the evaluation of the worst ground motions. Due to the unavailability of strong motion records, various attenuation relationships were adopted to calculate the peak ground acceleration (PGA) acting on dam sites. Krinitzsky [5] states that deterministic seismic hazard analysis considers geology and seismic history to identify earthquake sources and to interpret the strongest earthquake with regardless of time.
The probabilistic seismic hazard analysis is widely used and considers uncertainties in size, location and recurrence rate of earthquakes. Kramer [6] states that the probabilistic seismic hazard analysis provides a framework in which uncertainties can be identified and combined in a rational manner to provide a more complete picture of the seismic hazard.

For this study eight separate predictive relationships for horizontal peak ground acceleration were considered [7,8,9,10,11,12,13,14]. However, some data have been excluded for the study because of giving extreme values.

For the seismic hazard analysis of each dam site, all possible seismic sources were identified and their potential was evaluated in detail, as based on the guidelines [15] and the unified seismic hazard modeling for Mediterranean region introduced by Jiminez et al [16]. As a result of an extensive survey and a search of available literature, several sources have been identified to help analyzing the seismic hazard of dams in Turkey.

The data instrumentally recorded earthquakes for Turkey and vicinity collected by the National Disaster Organization were considered as a basis for the seismic hazard analyses. The earthquakes that occurred within the last 100 years were used for estimating seismic parameters. Throughout the study, seismic zones and earthquakes within the area having a radius of 100 km around the dam site were considered.

ICOLD states that the Maximum Credible Earthquake (MCE) is the largest reasonably conceivable earthquake magnitude that is considered possible along a recognized fault or within a geographically defined tectonic province [3]. According to this specification, the Safety Evaluation Earthquake (SEE) is defined as the maximum level of ground motion for which the dam should be designed or analyzed. For the dams with high total risk, it is recommended that the SEE should be characterized by a level of motion equal to that expected at the dam site from the occurrence of a deterministically-evaluated maximum credible earthquake or of the probabilistically-evaluated earthquake ground motion with a very long return period.

Earthquake definitions given by FEMA [17] were considered for seismic hazard analyses in this study. The Operating Basis Earthquake (OBE), which was defined by means of the probabilistic methods mentioned above, is the earthquake that produces the ground motions at the site that can reasonably be expected to occur within the service life of the project. MDE is normally characterized by a level of motion equal to that expected at the dam site from the occurrence of deterministically evaluated MCE. Safety Evaluation Earthquake (SEE) is the level of shaking for which damage can be accepted but for which there should be no uncontrolled release of water from the reservoir. Most of large dams in Turkey were analyzed by using these definitions in past [18].

3. SEISMIC HAZARD ANALYSES

For the seismic hazard analyses of the dam site in the Upper Aras basin, a detailed study was performed to identify all possible seismic sources, as based on the seismic zonation map of Turkey, given in Figure 2. The National Disaster Organization and other Institutes prepared the map for general use. But it was modified by the author and co-workers to use for dam projects at the Earthquake Research Center in Eskişehir Osmangazi University. Local geological features and seismic history were used to quantify the rate of seismic activity in the basin. As a result of detailed evaluation, total area covering all basins was separated into five seismic zones. Figure 3 introduces the model used for seismic hazard analyses of this study.

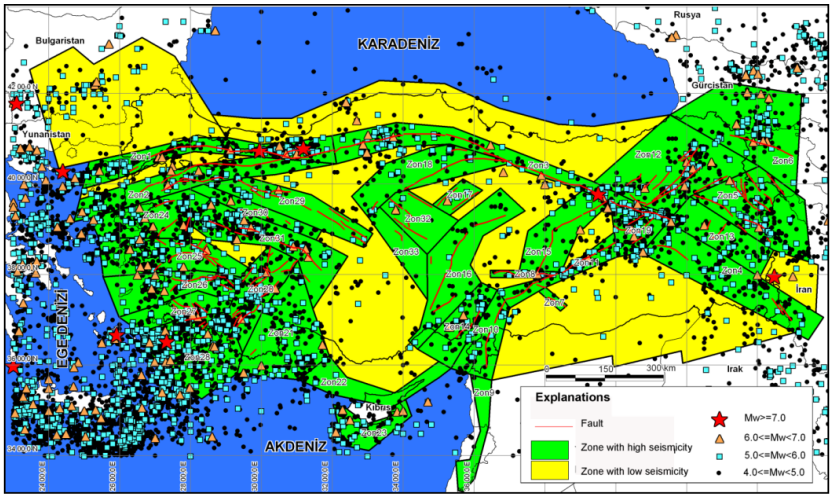

Figure 2. Seismo-tectonics model of Turkey

In Turkey, a new seismo-tectonic map was released to public by National Geological Survey [19]. In Turkey, a new seismo-tectonic map was released to public by National Geological Survey [19]. According to this map, only two dams considered for this study are under near source effect. ICOLD (2016) defined the near-field motion, which is ground motion recorded in the vicinity of a fault.

In this specification, a correlation between radius of near field area and earthquake magnitude is suggested as based on the cases on West United States. Author established limits of near-field motion for the investigation area. According to this model, there are two dams (Abbasgol and Unlendi), which are under the near-field motion. These two dams can be subjected to earthquake having a magnitude of 6.4 and 6.9 are the minimal distance to fault segment is 0.57 and 1.62 km, respectively. All dams excluding two dams discussed above are not under near-field motion (Table 1).

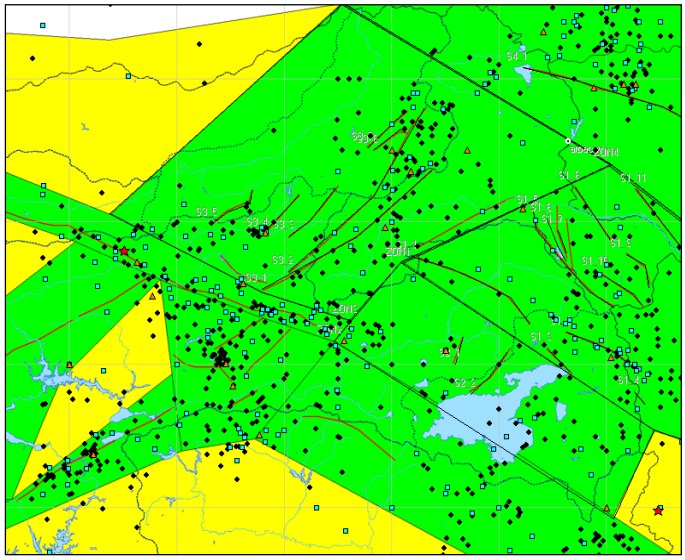

Figure 3. Seismological sources and earthquakes for the dams considered for the study area in Upper Aras basin

The deterministic analyses indicate that peak ground acceleration (PGA) changes within an acceptable range when excluded two dams, which are under the near near-field motion. The PGA values ranges from 0.106g to 0.317g for the mean Peak Ground Acceleration at the 50th percentile and from 0.176g to 0.511g for the mean Peak Ground Acceleration at the 84th percentile given in table 1. However, the PGA values are very high for the Abbasgol and Unlendi dams. The probabilistic hazard analyses give PGA values within a narrow range. The MDE values are between 0.132g and 0.298g, while the OBE values ranges from 0.099g to 0.243g, without considering two dams mentioned above.

Table 1. Results of deterministic and probabilistic analyses

N 0	Dam	Deterministic Method *				Probabilistic Method **		
		M_{max}	R_{min} (km)	Mean PGA + 50 %	Mean PGA + 84 %	OBE in g	MDE in g	SEE in g
1	Abbasgol	5.9	0.57	0.286	0.492	0.523	0.662	0.781
2	Arpacay	7.4	47.4	0.106	0.176	0.117	0.154	0.210
3	Çıldır	7.4	16.1	0.245	0.385	0.122	0.177	0.239
4	Digor	7.1	44.2	0.142	0.237	0.145	0.163	0.317
5	Demirdoven	6.9	21.9	0.195	0.325	0.233	0.298	0.391
6	Durancam	7.4	28.9	0.235	0.388	0.140	0.187	0.229
7	Karakurt	7.4	37.4	0.148	0.245	0.118	0.156	0.200
8	Kars	7.4	33.7	0.124	0.206	0.099	0.132	0.185
9	Kayabeyli	7.4	11.1	0.317	0.511	0.144	0.189	0.286
10	Kockoy	7.4	13.6	0.276	0.428	0.193	0.272	0.351
11	Koroglu	7.4	20.7	0.206	0.326	0.107	0.150	0.223
12	Kotanlı	7.4	15.3	0.254	0.398	0.123	0.177	0.254
13	Sefakoy	6.9	19.9	0.157	0.262	0.178	0.231	0.269
14	Selim-Bayburt	7.4	32.5	0.123	0.204	0.105	0.137	0.185
15	Sirinkoy	7.1	56.0	0.108	0.180	0.113	0.147	0.198
16	Tuzluca	6.7	20.1	0.188	0.208	0.243	0.295	0.387
17	Unlendi	6.1	1.62	0.289	0.467	0.482	0.609	0.726
18	Yedikasım	7.4	24.9	0.218	0.357	0.132	0.178	0.224

(*) M_{maks} = Maximum earthquake magnitude in M_w
R_{min} = Minimum distance to fault segment
Mean PGA + 50% = Mean Peak Ground Acceleration at the 50th percentile
Mean PGA + 84% = Mean Peak Ground Acceleration at the 84th percentile

(**) OBE= Operational Based Earthquake
MDE = Maximum Design Earthquake
SEE = Safety Evaluation Earthquake

4. RESULTS AND DISCUSSION

There are important dam structures in Upper Aras basins such as Arpacay, Demirdöven, Karakurt, Kayabeyli, Koroglu, Kotanli, Sefakoy and Selim dams. The dams, which are located on the main river of the basin, can cause very serious conditions for downstream life and property, when they fail or are damaged. Therefore, their earthquake safety will be evaluated more detail as given below.

Arpacay dam is one of the main structures of the basin with volume of 0.53 hm^3 of concrete gravity type (Figure 4). It is located on the Arpacay river (the Armenia border) in Aras basin. Its construction was started in 1975 and finished in 1983. Its height from river bed is 50.9 m (DSİ, 2016). When the reservoir is at operation stage with maximum water level, the facility approximately will impound 525 hm^3 of water with a reservoir surface area of 42 km^2. It is mainly designed to produce electricity with 13 MW of install capacity and to irrigate 70 520 ha of land. The alluvium on river bed was removed before beginning the construction of the main embankment. The seismic hazard analyses performed throughout this study indicates that this dam is one of safe dams within the Aras basin. It will be subjected to a peak ground acceleration of 0.106 g by an earthquake of 7.4 magnitude and it is only 47.4 km far away from an active fault.

Figure 4. A general view from Arpacay dam

Demirdoven dam is a earthfill dam 67-m high with a total embankment volume of 2 500 000 m^3. It is located on the Timar River in Upper Aras basin. Its construction was finished in 1996. When the reservoir is at operation stage with maximum water level, the facility approximately will impound 37.34 hm^3 of water. It was mainly designed to provide water for irrigation of 9 844 ha area. The crest length is 695 m and the side slopes of main embankment is 3.0H:1V for upstream and 2.5H:1V for downstream (H=horizontal and V=vertical). On the section there is a central impervious core, which is composed of compacted clay and a transition section of sand and gravel was designed between the core and earthfill materials for downstream part. The downstream shells are composed of natural earth materials with cover zone. The alluvium on river bed, which is composed of mixtures of fine to large size grains, was removed before beginning the construction of the main embankment. The seismic hazard analyses performed throughout this study indicates that Demirdoven dam is one of the safe dams within the basin. It will be subjected to a peak ground acceleration of 0.195g by an earthquake of 6.9 magnitude and it is not close to the fault segment (21.9 km).

The Karakurt dam is a rockfill dam with asphaltic core on the Aras River near Sarikamis County. It has a 137-m height from river bed. When the reservoir is at maximum capacity, the facility impounds 590 hm^3 of water. Its construction will be finished at the end of 2017. It was designed to produce electricity with an install capacity of 99.5 MW and flood controlling. The main embankment consists of crushed rock and transition zone to the central asphaltic core. According to the seismic hazard analyses of this study, it will be subjected to a peak ground acceleration of 0.148 g by an earthquake of 7.4 magnitude. It is identified as class III with high risk. Dam site is located 37.4 km for away from an active fault.

The Kayabeyli dam is a roller compacted concrete dam on the Kura River near Ardahan city in the Aras basin. It has a 155-m height and the facility impounds 148 hm^3 of water when the reservoir is at maximum capacity. Its construction was finished in 2016. It was designed to produce electricity with an install capacity of 87.5 MW. According to the seismic hazard analyses of this study, it will be subjected to a peak ground acceleration of 0.317g by an earthquake of 7.4 magnitude. Dam site is located 11.1 km for away from an active fault.

The Koroglu dam is a roller compacted concrete dam on the Kura River near Ardahan city in the Aras basin. It has a 170-m height and the facility impounds 73 hm^3 of water when the reservoir is at maximum capacity. Its construction was finished in 2016. Its system was designed to produce electricity with an install capacity of 50 MW. According to the seismic hazard analyses of this study, it will be subjected to a peak ground acceleration of 0.206g by an earthquake of 7.4 magnitude. Dam site is located 20.7 km for away from an active fault.

The Kotanli dam is a roller compacted concrete dam on the Kura River near Ardahan city in the Aras basin. It has a 59.5-m height and the facility impounds 20.4 hm^3 of water at maximum capacity of reservoir. Its construction was finished in 2016. This dam is a part of Koroglu-Kotanli energy system. According to the seismic hazard analyses of this study, it will be subjected to a peak ground acceleration of 0.254g by an earthquake of 7.4 magnitude. It is identified as class III with high risk. Dam site is located 15.3 km for away from an active fault.

Sefakoy dam is a earthfill dam 43-m high is located on the main river in Aras basin. Its construction was finished in 2012. When the reservoir is at operation stage with maximum water level, the facility approximately will impound 9.84 hm^3 of water. It was mainly designed to provide irrigation water for lands of Kagizman plain. On the section there is a central impervious core, which is composed of compacted clay and a transition section of sand and gravel was designed between the core and shell materials The alluvium on river bed, which is composed of mixtures of fine to large size grains, was removed before beginning the construction of the main embankment. The seismic hazard analyses performed throughout this study indicates that Sefakoy dam is one of the safe dams within the basin. It will be subjected to a peak ground acceleration of 0.157g by an earthquake of 6.9 magnitude and it is not close to the active fault segment (19.9 km).

Selim-Bayburt dam is a rockfill dam 57-m high with an embankment volume of 2.1 hm^3. It is located on the Bozkus river in Aras basin. Its construction was finished in 2003. When the reservoir is at operation stage with maximum water level, the facility approximately will impound 52.43 hm^3 of water. It was mainly designed to provide irrigation water for lands of Selim plain and domestic water for counties in the region. On the section there is a central impervious core, which is composed of compacted clay and a transition section of sand and gravel was designed between the core and shell materials. The seismic hazard analyses performed throughout this study indicates that Selim-Bayburt dam is one of the safe dams within the basin. It will be subjected to a peak ground acceleration of 0.123g by an earthquake of 7.4 magnitude and it is not close to the fault segment (32.5 km.

There are two dams, namely Abbasgol and Unlendi dams, are under the near-field motion when considered the new seismo-tectonic map of Turkey, introduced by MTA [19]. Abbasgol dam is not a very large dam when compared with others in the Basin and has risk class of II with moderate risk ratio. However, Unlendi dam is the most critical dam of the Aras basin. It is under near-field motion (1.62 km far away for critical fault segment).

5. CONCLUSIONS

For this study, eighteen large dams, which are located on different seismic zones of the Upper Aras basin, were analyzed to estimate their seismic hazard and risk classes, as based on the actual earthquakes occurred within the basin and structural features of dams. The most critical zone for the basin is Armenian Fault. As a result of this study, 75 % of the dams under operation stage have been identified as the dams in moderate hazard ratio. There are two dams (Abbasgol and Unlendi dams), which are under near-field motion in the basin. In other words, these dams are also under the impact of near source zone. However, other large dams are relatively safe structures when we consider public safety. This study also indicates that predictive relationship of Campbell and Bozorgnia [18] gives the PGA values with large variation for both deterministic and probabilistic analyses of the dams considered for this study. Author would like to point out a scientific fact that local predictive relationships or relationships, which were developed with considering similar seismo-tectonic environment, should be adopted to determine the seismic parameters to be used in dynamic analyses.

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