

Re-evaluation of Large Dams in Van Inner Basin, Turkey

Hasan Tosun¹

1- Full professor, Civil Engineering Department, Osmangazi University, Eskisehir, Turkey

Email: hasantosun26@gmail.com

Abstract

In Turkey, there are twenty-five river basins. One of them is Van Inner Basin, which is located near Iran border, having 1.79 million hectares of surface area in East Turkey. This basin includes more than 40 dams. Most of them are small embankment dams. Major earthquakes with the potential of threatening life and property occur frequently in the basin. A national safety program was commenced to re-evaluate large dams of the basin. This paper summarizes the methods considered for earthquake safety evaluation and introduces the results of the study, which was performed for six large dams, namely Kockopru, Morgedik, Patnos, Sarımeşmet, Sihke and Zerneç dams in Van Inner basin. The seismic hazard analyses have indicated that peak ground acceleration changes within a wide range for dam sites of this area. The total risk analyses depending on the seismic hazard rating of dam site and risk rating of the structure have concluded that most of these large dams have high-risk class and can need design and construction measures to tolerate requirements resulting from updated seismic codes.

Keywords: Embankment dam, seismic hazard, total risk.

1. INTRODUCTION

There are so many factors acting on total risk for dam structures. Two of them, namely seismic hazard rating of dam site and risk rating of the dam and appurtenant structures, most important factors for total risk of dams. The seismic hazard of a dam site is based on the peak ground acceleration. The risk rating of the dam is defined on the basis of capacity of the reservoir, height of the dam, evacuation requirements and 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].

Total number of large dams constructed throughout all country is more than 1250 in Turkey. Most dams are of the embankment type. However, number of concrete dams and rolled compacted concrete dams increases recently. Most of the dam engineers 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. However, authors think that strong ground shaking can result in the instability of the embankment and loss of strength at the foundations, especially for dams which are under near source effect.

Van Inner Basin is located near Iran border, having 1.79 million hectares of surface area in East Turkey and includes more than 40 dams. Most of them are small embankment dams. Major earthquakes with the potential of threatening life and property occur frequently in the basin. The significant earthquake with a magnitude (M_w) of 7.2 took place on October 23, 2011 near Lake Van [4]. The epicenter is about 30 km to the north of Van city center. Because of its shallow focal depth of about 10 km the ground shaking in the epicentral region was very severe. The national seismo-tectonic map was updated as including new structural features in 2013. The investigation area is structurally cut by secondary faults, which are resulted by two main-faulting system throughout country. Another earthquake with magnitude of M_w 7.3 (Halabja Earthquake), which took place at Iran-Iraq border in 2017, was close to the investigation area [5]. 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 hydraulic height between 11.2 m and 62.4 m, in the Van Inner Basin (Figure 1). In the basin, more than ten large dams have been designed to exploit energy and irrigational potential of the basin. In this study six of them, which are under operation now, are considered in this study. Their physical properties are summarized in Table 1.

2. METHODS OF ANALYSES

The deterministic and probabilistic seismic hazard analyses are generally used for the study of seismic activity for dam sites. 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. Krinitzky [6] 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 [7] 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.

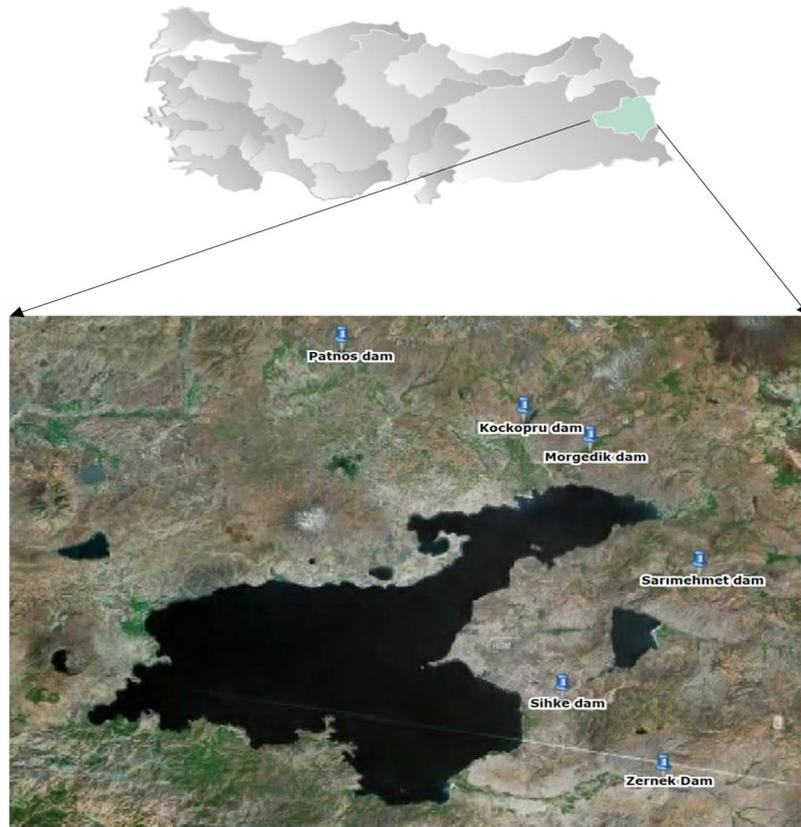


Figure 1. Location of dams considered for this study [8].

Table 1-Physical properties of large dams considered for this study.

#	Dam	Aim (*)	Height from river bed (m)	Completed Year	Type (**)	Volume of embankment (hm ³)	Volume of reservoir (hm ³)
1	Kockopru	I+E+F	51.0	1992	EF	2.0	86.5
2	Morgedik	I	55.0	2014	RF	0.7	102.5
3	Patnos	I	32.0	1991	EF	1.3	33.4
4	Sarımeşmet	I	47.0	1991	RF	1.2	133.3
5	Sihke	I+D	11.2	1957	EF	0.4	9.2
6	Zerne	I+E+F	62.4	1988	RF	2.1	105.8

* E: Energy I: Irrigation F: Flood control D: Domestic Water

** RF: Rockfill EF: Earthfill

For the dams in Van Inner Basin eight separate predictive relationships for horizontal peak ground acceleration were considered [9-16]. However, some data have been excluded for the study because of giving extreme values. For each dam site all possible seismic sources were identified and their potential was evaluated in detail, as based on the guidelines [17] and the unified seismic hazard modeling for Mediterranean region introduced by

Jiminez et al [18]. 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.

International Commission on Large Dams (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 [19] 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 [20,21]. Throughout this study, two methods have been considered to determine total risk of the dams. In DSI guidelines, total risk factor depends to reservoir capacity, height, evacuation requirement and potential hazard [22]. The Bureau method, which considers dam type, age, size, downstream damage potential and evacuation requirements, was utilized to realize the risk analyses of the basin. It recommends four separate risk classes ranging from I (low risk) to IV (extreme risk) as based on the Total Risk Factor (TRF). If the TRF is between 2 and 25, the risk class of dam is I (low). If the TRF is ranging from 25 to 125 and from 125 to 250, the risk classes of dam is II (moderate) and III (high), respectively. If the TRF is greater than 250, the risk class of dam is IV (extreme).

3. SEISMIC HAZARD ANALYSES

For the dam sites in the Van Inner Basin, a detailed study was performed to identify all possible seismic sources, as based on the seismic zonation map of Turkey, given in Fig. 2. The map for general use, prepared by the National Disaster Organization and other Institutes, was modified by the author and co-workers to use for dam projects. 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 three seismic zones. Fig. 3 introduces the model used for seismic hazard analyses of this study.

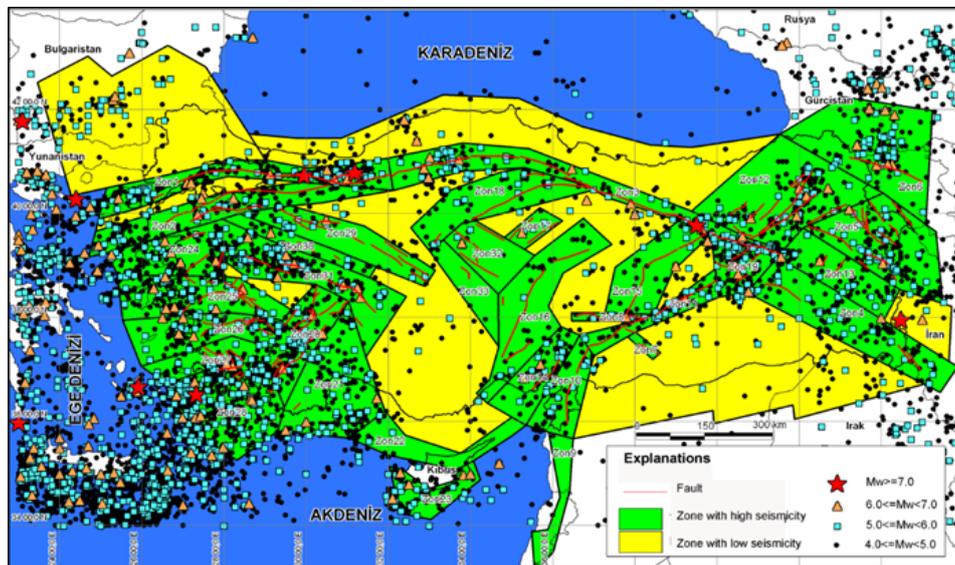


Figure 2. Seismo-tectonics model of Turkey

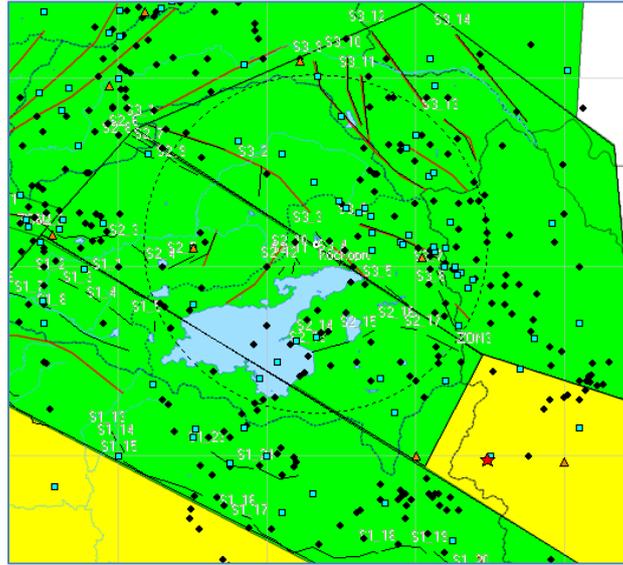


Figure 3. Seismological sources and earthquakes for the study area.

In Turkey, a new seismo-tectonic map was released to public by National Geological Survey [23]. ICOLD [3] 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. Authors established limits of near-field motion for the investigation area. According to this model, there are three dams, which are under the near-field motion. These dams can be subjected to earthquake having a magnitude (M_w) between 6.0 and 6.2 and the minimal distance to fault segment is between 3.0 and 29.6 km, respectively. Three dams are not under near-field motion (Table 2).

Table 2-Results of deterministic and probabilistic analyses.

#	Dam	Deterministic Method *				Probabilistic Method **		
		M_{max}	R_{min} (k m)	Mean PGA + 50 (%)	Mean PGA + 84 (%)	OBE in g	MDE in g	SEE in g
1	Kockopru	6.1	4.0	0.283	0.481	0.448	0.570	0.750
2	Morgedik	6.1	3.0	0.304	0.515	0.513	0.649	0.884
3	Patnos	6.1	22.8	0.101	0.172	0.185	0.234	0.302
4	Sarımehmet	6.0	12.1	0.160	0.272	0.348	0.455	0.567
5	Sihke	6.2	9.8	0.196	0.333	0.355	0.458	0.611
6	Zernek	6.0	29.6	0.080	0.136	0.186	0.232	0.297

- (*) M_{max} = 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

The deterministic analyses indicate that peak ground acceleration (PGA) changes within an acceptable range when excluded three dams, which are under the near near-field motion. The PGA values ranges from 0.080g to 0.304g for the mean Peak Ground Acceleration at the 50th percentile and from 0.136g to 0.515g for the mean Peak Ground Acceleration at the 84th percentile given in table 2. However, the PGA values are high for the Kockopru and Morgedik dams. The probabilistic hazard analyses introduce PGA values within a wide range. The MDE values are between 0.232g and 0.458g, while the OBE values ranges from 0.185g to 0.355g, without considering two dams mentioned above.

4. TOTAL RISK ANALYSES

The results related with total risk of the dams are given Table 3. One dam (Zernek) is classified into low hazard ratio with class I while three of them have moderate hazard rating with hazard class of II. Others are identified in class of IV with extremely high hazard rating. Two dam sites According to ICOLD (1989) classification, if the PGA value is greater than 0.25 g and the energy source is closer than 10 km from the dam site, it is classified as hazard class IV with hazard rating of extreme. For three dams, the distance from dam site to active faults, which are given on updated seismic maps, ranges from 3.0 km to 9.8 km. The large dams of basins, which are under the influence of the near-field motion, have been constructed to very close to active segments of the normal fault system in East Anatolia.

Table 3-Total risk of dams considered for this study.

#	Dam	Hazard Analysis		Total Risk (ICOLD,1989)			Total Risk (Bureau, 2003)		
		Class	Hazard Ratio	Risk factor	Risk class	Risk ratio	Risk factor	Risk class	Risk ratio
1	Kockopru,	IV	Very high	34	IV	Very high	197.68	III	High
2	Morgedik,	IV	Very high	30	III	High	120.18	II	Moderate
3	Patnos,	II	Moderate	24	III	High	86.59	II	Moderate
4	Sarimehmet	II	Moderate	36	IV	Very high	126.71	III	High
5	Sihke	II	Moderate	16	II	Moderate	102.02	II	Moderate
6	Zernek	I	Low	30	III	High	98.71	II	Moderate

According to DSI Guidelines all dams are categorized in II, III and IV risk classes with moderate, high and very high risk rating. Following Bureau's method, all large dams with exception of Kockopru and Sarimehmet dams are classified in risk class II with moderate-risk rating. The solution obtained from Bureau method is more rational than those estimated by the DSI guidelines.

The values of the TRF range from 86.6 to 197.7 as based on Bureau method. This means that there is no dam having a risk class of I in the basin. There are four dams of a risk class of II and two dams of a risk class of III. In other words, thirty-three percent of total dams are identified approximately as a risk class of III, while the rest are identified as class of II.

5. RESULTS AND DISCUSSIONS

In this study six large dams have been considered for their seismic hazard and total risk. Some of them, which are located on the main rivers of the basin and near metropolitan area, can cause very serious conditions for downstream life and property, when they fail. Therefore, their earthquake safety will be evaluated more detail as given below.

Kockopru dam is one of the main structures of the basin with volume of 2.0 hm³ of earthfill type (Figure 4). Its construction was completed in 1992. Its height from river bed is 51.0 m [8]. When the reservoir is at operation stage with maximum water level, the facility approximately will impound 86 hm³ of water with a reservoir surface area of 21.0 km². The crest length is 700 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) (Figure 5). On the section there is a central impervious core, which is composed of compacted clay and a transition section of sand was designed between the core and earthfill materials for both sides. The toe of downstream shells was supported by removed rock material. It is mainly designed to produce electricity with 8.5 MW of install capacity and to irrigate 9 295 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 critical dams within the basin. It will be subjected to a peak ground acceleration of 0.283 g by an earthquake of 6.1 magnitude and it is only 4.0 km far away from an active fault. its risk is also high for downstream life.

Morgedik dam is a rockfill dam with a total embankment volume of 0.7hm³ Its height from river bed is 55.0 m. Its construction was finished in 2014. When the reservoir is at operation stage with maximum water level, the facility approximately will impound 102.5 hm³ of water. It was mainly designed to provide water for irrigation. The materials on river bed were removed before beginning the construction of the main embankment. The seismic hazard analyses performed throughout this study indicates that Morgedik dam is one of the critical dams within the basin. It will be subjected to a peak ground acceleration of 0.304g by an earthquake of 6.1 magnitude and it is close to the fault segment (3.0 km).



Figure 4.A general view from Kockopru dam.

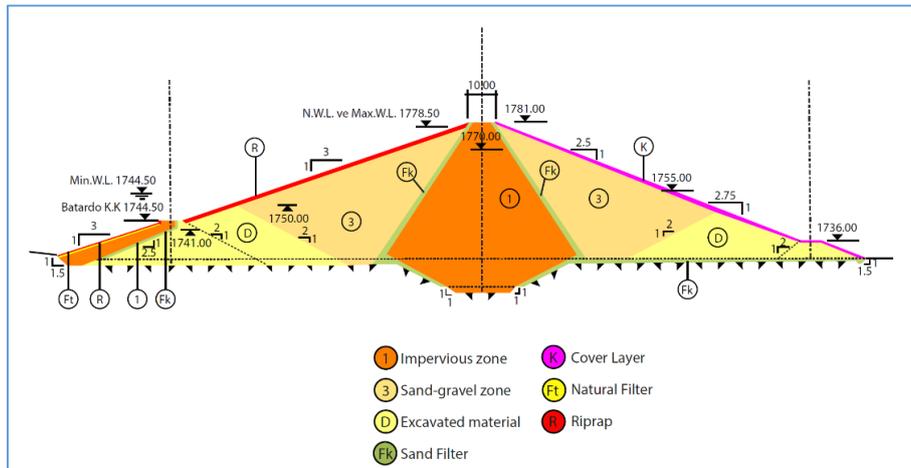


Figure 5.The maximum cross-section of the embankment of Kockopru dam.

The Patnos dam is a earthfill dam located near Patnos Province. It has a 32 m height from river bed. When the reservoir is at maximum capacity, the facility impounds 33.4 hm³ of water. Its construction will be finished at the end of 1991. It was designed to irrigate lands in Patnos plain and also provide flood controlling. According to the seismic hazard analyses of this study, it will be subjected to a peak ground acceleration of 0.01 g by an earthquake of 6.1 magnitude. It is identified as class III with high risk according to ICOLD specification while it is categorized into class II with moderate risk (TRF=86.6). Dam site is located 22.8 km for away from an active fault.

The Sarimehmet dam is a earthfill dam on the Karasu River of Van Inner Basin. It has a 62.0-m height from foundation and the facility impounds 133.3 hm³ of water with a reservoir surface area of 17.4 km². when the reservoir is at maximum capacity (Figure 6). Its construction was finished in 1991. The crest length is 204.4 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) (Figure 5). On the section there is a central impervious core, which is composed of compacted clay and a transition section of sand was designed between the core and earthfill materials for both sides. It was designed mainly to irrigate land of 17 700 ha. and also to produce electricity with an installed capacity of 3.5 MW. According to the seismic hazard analyses of this study, Sarimehmet dam is not a critical structure of Van Inner Basin that it will be subjected to a peak ground acceleration of 0.160g by an earthquake of 6.1 magnitude. Dam site is located 12.2 km for away from an active fault.

The Sihke dam is a earthfill dam within the metropolitan area of Van city. Its construction was finished in 1957. It has a 11.2-m height from river bed and the facility impounds 9.2 hm³ of water when the reservoir is at maximum capacity. Its system was mainly designed to provide water for local irrigation and recreation. According to the seismic hazard analyses of this study, it will be subjected to a peak ground acceleration of

0.196g by an earthquake of 6.2 magnitude. Dam site is located 9.8 km for away from an active fault. Sihke dam is the oldest structure of the basin and has high total risk for downstream life. Its seismic stability should be upgraded soon.



Figure 6.A general view from Sarimehmet dam.

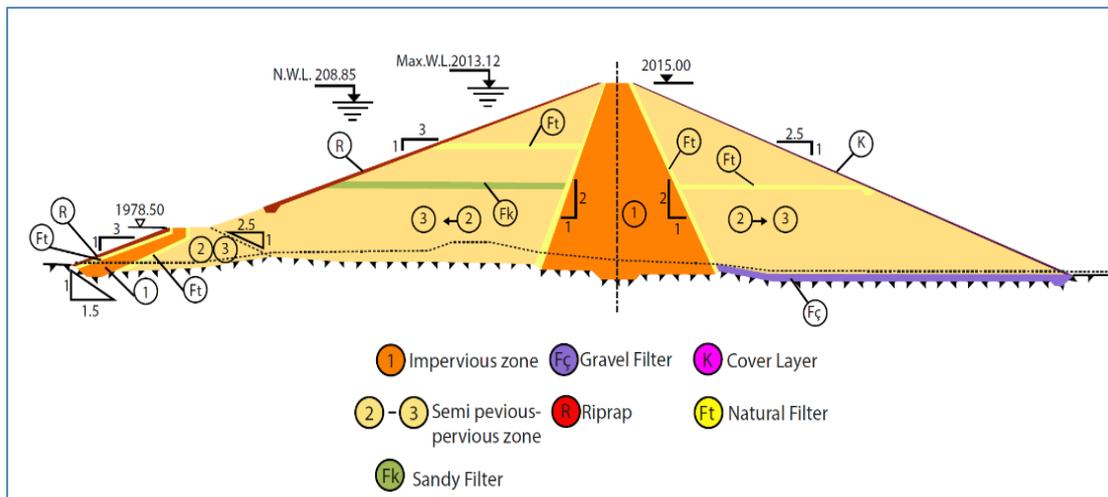


Figure 7.The maximum cross-section of embankment for Sarimehmet dam.

Zernek dam is one of the main structures of the basin with volume of 2.1 hm³ of earth-rockfill type (Figure 8). Its construction was completed in 1992. Its height from foundation is 80.0 m [8]. When the reservoir is at operation stage with maximum water level, the facility approximately will impound 105.8 hm³ of water with a reservoir surface area of 20.4 km². The crest length is 246 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) (Figure 9). On the section there is a central impervious core, which is composed of compacted clay and a transition section of sand was designed between the core and earthfill material for upstream shell and rockfill material for downstream shell. It is mainly designed to produce electricity with 4.5 MW of install capacity and to irrigate 10 300 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 not critical structure within the basin as based the current seismic data. It will be subjected to a peak ground acceleration of 0.080g by an earthquake of 6.0 magnitude and it is 29.6 km far away from an active fault. its risk is at moderate level for downstream life.



Figure 8.A general view from Zernek dam.

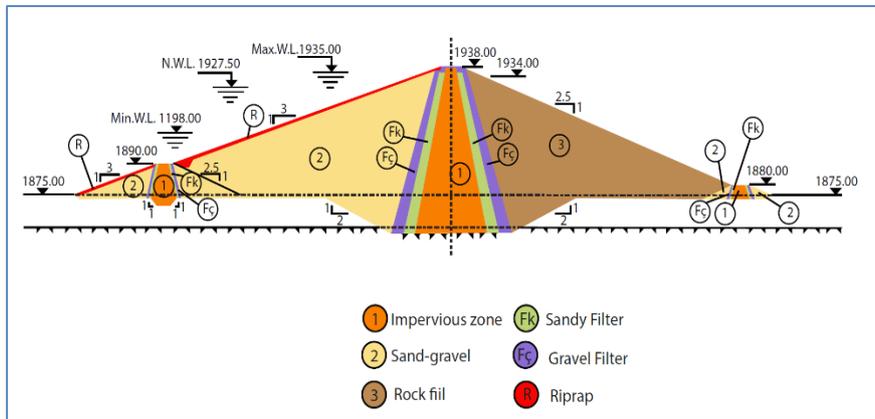


Figure 9. The maximum cross-section of embankment for Zernekdam.

There are three dams are under the near-field motion when considered the new seismo-tectonic map of Turkey, introduced by MTA (2013). The analyses indicate that Kockopru and Sarimehmet dams are the most critical structures of the Van Inner Basin.

6. CONCLUSIONS

For this study, six large dams, which are located on different seismic zones of the Van Inner 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. As a result of this study, thirty-three percent of the dams under operation stage have been identified as the dams in very high hazard ratio, while fifty percent of dams are classified in moderate hazard ratio. There are three dams, which are under near-field motion in the basin. In other words, these dams are under the impact of near source zone. Especially Kockopru and Sarimehmet dams are the most critical structures of the Van Inner Basin. However, other large dams are relatively safe structures when we consider public safety. Author points out a fact that local predictive relationships or relationships, which were developed with considering similar seismo-tectonic environment, should be used to determine the seismic parameters to be used in dynamic analyses

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