SAFETY EVALUATION FOR OLDER LARGE DAMS IN TURKEY

H. TOSUN
Full Professor, Eskisehir Osmangazi University, Eskisehir, Turkey

ABSTRACT

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 1250. Most dams are of the embankment type. First systemic design was commenced at the end of first quarter of 1900'years. Eight older large dams, namely Cubuk-1, Golbasi, Gebere, Sihke, Porsuk, Sariyar, Kemer and Hirfanli were constructed between 1936 and 1959. They are older than 60 years. Three of them were constructed for producing electricity with an installed capacity of 48 to 128 MW, while others have been designed to exploit irrigational potential of the lands and to provide domestic water to cities in Turkey. During the period of their design, there was no seismic hazard and total risk analyses. This paper summarizes main principles of seismic design for existing dams and deals with an evaluation of seismic hazard and total risk of the large older dams, which have a hydraulic height ranging height from 11 to 109 m throughout all country. The analyses indicate that most of dams should be redesigned to provide necessary conditions and additional construction measures should be taken into account for providing public safety in downstream people and properties.

1. INTRODUCTION

Seismic evaluation of existing dam differs from the design of new one. On the seismic evaluation of existing embankment dams, designers try to accomplish in accordance with current regulations and specifications. However, upgrading existing embankment dams due to current seismic design standards is generally expensive and evaluation is carried out with a risk-informed process considering various factors. In Turkey, there are so many large dams, which are under near field effects according to the seismic zonation map introduced in 2012 and the regulation for seismic design of dams has been updated in 2013.

Case studies indicate that embankment dams should withstand the design earthquake without damages or with little damages of acceptable level. Turkey is located on one of the most seismically active regions in the world. Major earthquakes with the potential of threatening life and property occur frequently here. Significant structural damage had developed at a number of dams, but no failures have been reported.

Earthquake effect on dams depends on dam types. Dam scientists stated that safety concerns for embankment dams subjected to earthquakes involve either the loss of stability due to a loss of strength of the embankment and foundation materials or excessive deformations such as slumping, settlement, cracking and planer or rotational slope failures. According to Jansen (1988), safety requirements for concrete dams subjected to dynamic loadings should involve evaluation of the overall stability of the structure, such as verifying its ability to resist induced lateral forces and moments and preventing excessive cracking of the concrete.

In this paper, the analyses for eight old dams located on different locations throughout country, are briefly given and their results are comparatively discussed as based on new seismic design criteria adopted in Turkey (DSI, 2012). They are still operated for multi-purposes. Three of them are effectively used for producing electricity. Their installed capacities range from 48 to 128 MW. Table 1 introduces the physical properties of dams considered for this study.

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

#	Dam	Basin	River	Height from river bed (m)	Function (*)	Type (**)	Completed year	Body Volume (hm³)	Reservoir Capacity (hm³)
1	Cubuk-1	Sakarya	Cubuk	25	D+F	CG	1936	0.12	5.6
2	Golbasi	Susurluk	Nilufer	14	I	EF	1938	0.48	12.8
3	Gebere	Konya	Uzandi	13	I	EF	1941	0.16	2.4
4	Sihke	Van	Sihke	11.2	I+R	EF	1948	0.40	9.2
5	Porsuk	Sakarya	Porsuk	50	I+D+F	CG	1949	0.19	454
6	Sariyar	Sakarya	Sakarya	80	E	CG	1956	0.57	1 900
7	Kemer	B.Menderes	Akcay	109	E+I+F	CG	1958	0.74	432
8	Hirfanli	Kizilirmak	Kizilirmak	78	E+F+I	RF	1959	2.00	5 980

E = Energy I = Irrigation F= Flood control R= Recreation

(**) EF =Earthfill RF = Rockfill CG = Concrete Gravity

2. METHODS AND MATERIALS

Deterministic and probabilistic seismic hazard analyses are generally used for seismic study of dams. 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 (2005) 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 (1996) 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 five separate predictive relationships for horizontal peak ground acceleration were considered (Campbell, 1981; Boore et al, 1993; Ambraseys et al, 1995; Boore et al, 1997 and Kalkan &Gulkan, 2004). For the hazard analysis of dam sites, all possible seismic sources were identified and their potential was evaluated in detail, as based on the guidelines given by Fraser and Howard (2002) and the unified seismic hazard modelling for Mediterranean region introduced by Jiminez et al (2001). 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 (2016) recently defined the Operating Basis Earthquake (OBE) and the Safety Evaluation Earthquake (SEE). In this study, earthquake definitions given by FEMA (2005) were considered for seismic hazard analyses, 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. The Operating Basis Earthquake (OBE) is known as the earthquake that produces the ground motions at the site that can reasonably be expected to occur within the service life of the project. It will be appropriate to choose a minimum return period of 145 years. It means a 50 percent probability of not being exceeded in 100 years. 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.

Countries pose their own specification for selecting design earthquakes. Table 2 introduces the limitations in seismic design of dams. It was also stated that the seismic coefficient is equal to the peak ground acceleration (PGA) when the value of PGA, which is obtained by deterministic method, is less than 0.22g. Otherwise, a formula should be considered for determining the seismic coefficient to be used for pseudo-static analysis (DSI, 2012).

Table 2 : Selection of Design Earthquake as based on risk classification (DSİ, 2012)

Hazard Analysis		Deterministic Method	Probabilistic Method
Class	Hazard Ratio		
I	Low	50 %	T_R = 224 years (*)
II	Moderate	50 %	T_R = 475 years
III	High	84 %	T_R = 975 years
IV	Very high	84 %	T_R = 2475 years

(*) Tr = Return time

There are various methods to quantify total risk for dams One of them, recommended by ICOLD(1989), considers the seismic hazard of the dam site and the risk rating of the structure separately. According to this method, the seismic hazard of the dam site regardless of type of dam, can be classified into four groups from low to extreme. This is a quick way for rating the seismic hazard. The hazard class of a dam site obtained from this method provides a preliminary indication of seismic evaluation requirements. DSİ Specification (DSI, 2012) considers the ICOLD method for total risk of dams.

Another of total risk classification is Bureau method, which considers various risk factors and weighting points to quantify the total risk factor (TRF) of any dam. Bureau (2003) states that TRF depends on the dam type, age, size, downstream risk and vulnerability, which depends on the seismic hazard of the site.

3. ANALYSES

For the seismic hazard analyses of the dam site in the basins, a detailed study was performed to identify all possible seismic sources, as based on the macro seismo-tectonic model of Turkey. Fig. 1 introduces the model used for seismic hazard analyses of this study.

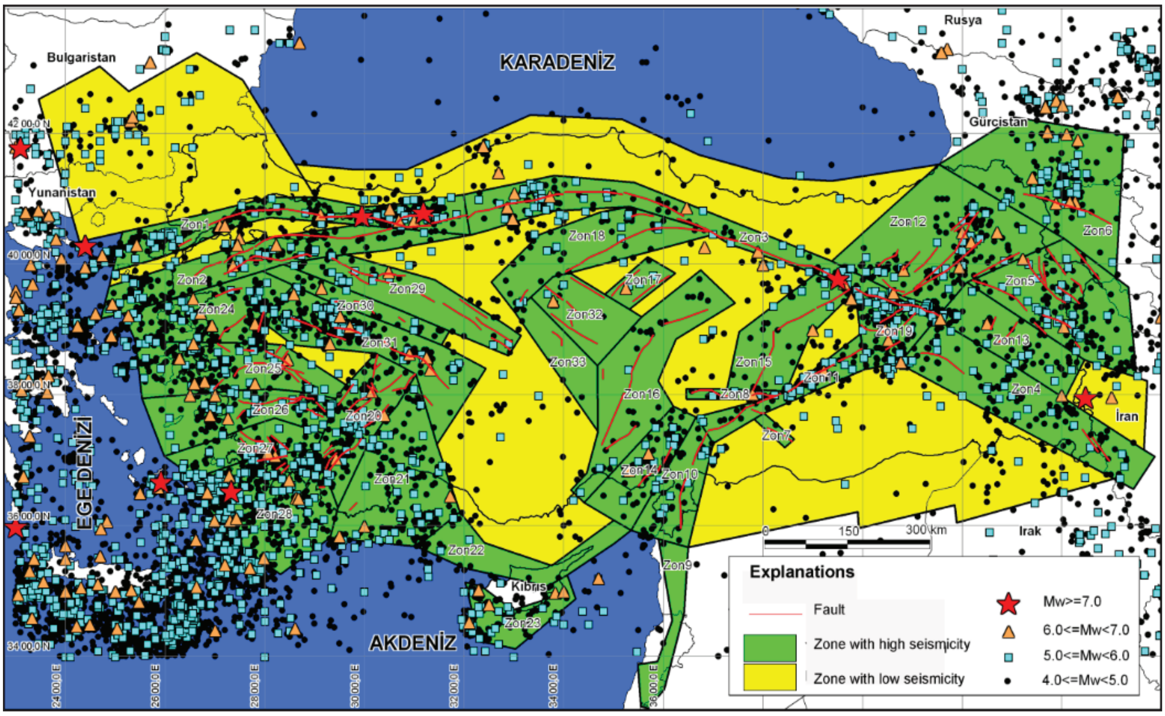

Figure 1 : Seismo-tectonics model of Turkey

In Turkey, a new seismo-tectonic map was released to public by National Geological Survey (MTA, 2013). According to this map, all existing 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, the maximum magnitude of the earthquakes is different for the dams considered in this study and the minimal distance to fault segment is between 1.0 and 9.8 km for critical dams (Table 3).

Table 3 : Results of seismic hazard analyses

No	Dam	Deterministic Method *				Probabilistic Method **		
		M_{max}	R_{min} (km)	Mean PGA + 50 % in g	Mean PGA + 84 % in g	OBE in g	MDE in g	SEE in g
1	Cubuk-1	6.1	21.8	0.104	0.177	0.125	0.173	0.243
2	Golbasi	6.5	4.4	0.307	0.521	0.317	0.427	0.600
3	Gebere	6.8	16.4	0.158	0.264	0.104	0.141	0.202
4	Sihke	6.2	9.8	0.196	0.333	0.355	0.458	0.611
5	Porsuk	5.8	6.7	0.259	0.420	0.361	0.469	0.627
6	Sariyar	6.1	4.1	0.252	0.425	0.247	0.344	0.494
7	Kemer	6.8	1.0	0.438	0.695	0.445	0.559	0.713
8	Hirfanli	6.3	19.5	0.120	0.203	0.108	0.145	0.206

(*) 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 a wide range. The PGA values ranges from 0.104g to 0.438g for the mean Peak Ground Acceleration at the 50th percentile and from 0.177g to 0.695g for the mean Peak Ground Acceleration at the 84th percentile given in Table 3. The probabilistic hazard analyses give PGA values within a narrow range. the MDE values are between 0.141g and 0.559g, while the OBE values ranges from 0.125g to 0.445g. According to DSI guidelines, designers have to use the PGA values at the 84th percentile for four large dams (Golbasi, Porsuk, Sariyar and Kemer) analyzed throughout the study, when considered deterministic approach (DSI, 2012).

The seismic hazard analyses were performed for eight older dams. The results with total risk of each dam are given in Table 4. Four of them are identified in class of IV with extremely high hazard rating. 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. Throughout this study dams, which are located at the shear zone, have a hazard class of IV. For these dams, the distance from dam site to active faults, which are given on updated seismic maps, ranges from 1.0 km to 6.7 km. The large dams of shear zone, which are under the influence of the near-field motion, have been constructed to very close to active segments of the faulting system, which were determined after 2013.

Throughout this study, two methods have been considered for the total risk for dam structures. In DSI guidelines, total risk factor depends to reservoir capacity, height, evacuation requirement and potential hazard (DSİ, 2012). The Bureau (2003) 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).

Table 4 : Results of total risk analyses for all dams considered in the study

#	Dam	PGA in g	M_{max}	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	Cubuk-1	0.068	6.1	II	Moderate	26	III	High	132.0	III	High
2	Golbasi	0.307	6.5	IV	Very High	20	III	High	153.2	III	High
3	Gebere	0.158	6.8	II	Moderate	12	II	Moderate	106.5	II	Moderate
4	Sihke	0.196	6.2	II	Moderate	16	II	Moderate	102.0	II	Moderate
5	Porsuk	0.259	5.8	IV	Very High	36	IV	Very high	170.2	III	High
6	Sariyar	0.252	6.1	IV	Very High	36	III	High	170.9	III	High
7	Kemer	0.4.38	6.8	IV	Very High	36	IV	Very high	175.0	III	High
8	Hirfanli	0.120	6.3	II	Moderate	32	III	High	148.2	III	High

According to DSI Guidelines all dams are categorized in II, III and IV risk classes with moderate and extreme high risk rating. Following Bureau's method, six large dams are classified in risk class III, a high-risk rating. The results obtained from Bureau method is more rational than those estimated by the DSI guidelines. The TRF data range from 102.0 to 170.9 as based on Bureau method. This means that there is two dam having a risk class of II in the zone. There are six dams in risk class of III. In other words, seventy-five percent of dams are identified as a risk class of III with high risk ratio.

4. DISCUSSION

The Golbasi, Porsuk, Sariyar and Kemer dams pose the PGA values of 0.307g, 0.259g, 0.252g and 0.438g, respectively when considered new seismic data base in Turkey. The geology of dam sites are complicated and are very close to the energy zone. The author points out the fact that four dams, which are located on a shear zone of faulting system, have high risk for downstream life. These are Porsuk, Sariyar, Kemer and Hirfanli dams. Kemer dam is the most critical one when considered total risk of the hydraulic system in Great-Menderes River Valley. Three dams are briefly discussed below as based on the updated seismic data base.

Kemer Dam

The Kemer dam is a concrete gravity dam on the Akçay River near Nazilli city in the Great Menderes basin. It has a 114-m height from foundation and the facility impounds 432 hm^3 of water when the reservoir is at maximum capacity. Its construction was finished in 1958. Its system was mainly designed to produce electricity with an install capacity of 48 MW and also to irrigate land of 58 259 ha. According to the seismic hazard analyses of this study, it will be subjected to a peak ground acceleration of 0.438g by an earthquake of 6.8 magnitude. Dam site is located 1.04 km for away from an active fault. Kemer dam is the oldest structure of the Great Menderes basin and has high total risk for downstream life. Tosun et al (2019) evaluated its seismic stability and total risk within the basin in detail. The 62-years old embankment is now in good condition, but it cannot meet current seismic design standards. Therefore, its seismic upgrade should be provided soon.

Sariyar Dam

The Sariyar dam is a concrete gravity dam on the main river of Sakarya Basin. It has a 108-m height from foundation. When the reservoir is at maximum capacity, the facility impounds 1 900 hm^3 of water with a reservoir surface area of 83.83 km^2. Its construction was finished in 1956. It was designed to generate electricity with a install capacity of 160 MW. According to the seismic hazard analyses of this study, it will be subjected to a peak ground acceleration of 0.252 g by an earthquake of 6.1 magnitude. It is identified as class III with high risk. Dam site is located 1.0 km far away from an active fault. Sariyar dam is the oldest structure of the Sakarya basin and has high total risk for downstream life. The 64-years old embankment is now in good condition, but it cannot meet current seismic design standards. Concrete aging problem can be seen in the main body of dam. Fig. 2 shows a general view from Sariyar dam.

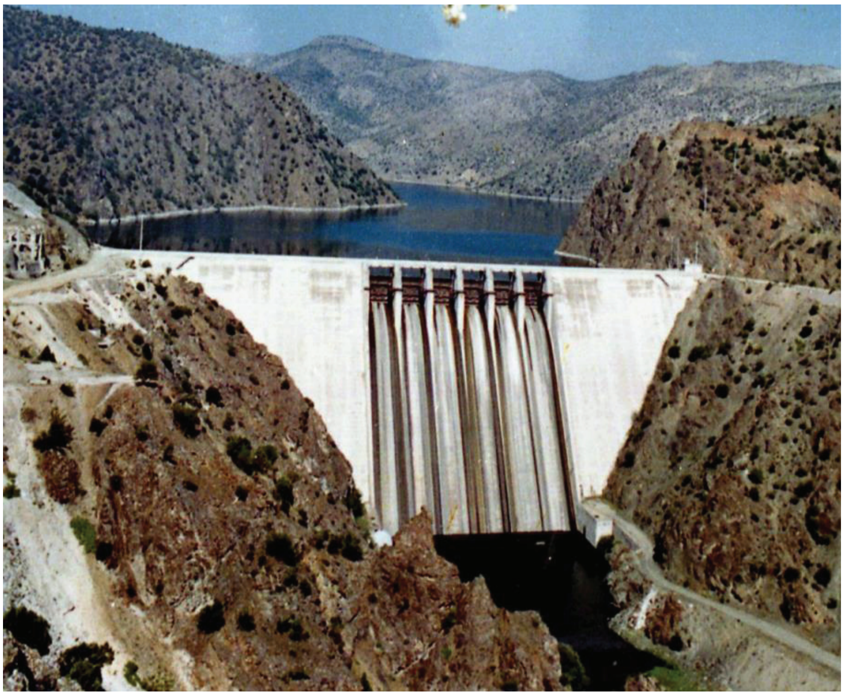

Figure 2 : A general view from Sariyar dam

Porsuk Dam

Porsuk dam is a concrete gravity dam on the Porsuk river of Sakarya Basin. It has a 65-m height from foundation and the facility impounds 454 hm^3 of water when the reservoir is at maximum capacity. Its primary construction was finished in 1949. However, it was heighted in 1959. Its system was mainly designed to provide domestic water (32 hm^3 per year) for Eskisehir city and also to irrigate land of 24 850 ha. According to the seismic hazard analyses of this study, it will be subjected to a peak ground acceleration of 0.259g by an earthquake of 5.8 magnitude. Dam site is located 6.7 km for away from an active fault. Porsuk dam is the one of older structures of the Sakarya basin and has high total risk for downstream life. The 71-years old embankment is now in good condition, but it cannot meet current seismic design standards. Therefore, its seismic upgrade should be provided soon. Concrete aging problem has been observed on the main body and appurtenant structures of dam.

Hirfanlı Dam

The Kilickaya dam is a rockfill dam with inclined clay core on the main river of Kizilirmak Basin. It has a 83-m height from foundation. When the reservoir is at maximum capacity, the facility impounds 5 980 hm^3 of water with a reservoir surface area of 263 km^2. Its construction was finished in 1959. It was designed to generate electricity with a install capacity of 128 MW. The side slopes of main embankment is 2.4H:1V for upstream and 1.3H:1V for downstream (H=horizontal and V=vertical). On the section there is a inclined impervious core, which is composed of compacted low plasticity clay and a transition section was designed between the core and rockfill materials for downstream part. 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. A general view from Kilickaya dam and its embankment detail are given in Fig. 3 and 4, respectively.

The seismic hazard analyses performed throughout this study indicates that Hirfanli Dam is not critical dam within the basin. It will be subjected to a peak ground acceleration of 0.120g by an earthquake of 6.3 magnitude and it is not close to the fault segment (19.5 km). It is also classified into the risk class of III with high risk according DSI specification. It is safe when considered the k-values, which are calculated according to mean peak ground acceleration at the 50^{th} percentile. However, it is not safe when used the k-value, which are calculated according to mean peak ground acceleration at the 84^{th} percentile as based on table 2. The 61-years old embankment is now in good condition, but it cannot meet current seismic design standards. Therefore, its seismic upgrade should be provided soon.

Figure 3 : A general view from Hirfanli dam.

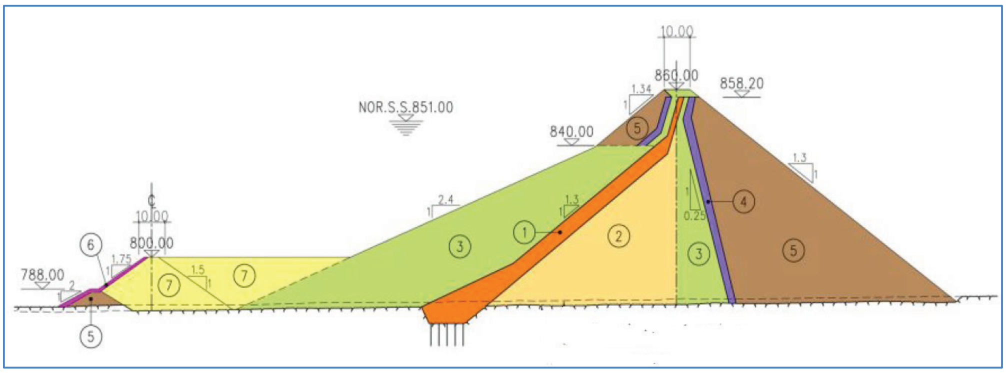

Figure 4 : Maximum cross-section of the embankment of Hirfanli dam (1:Impervious clay, 2: Fine crushed rock, 3: Coarse crushed rock, 4:Filter, 5: rock fill, 6: Cover layer and 7: Weathered rock).

5. CONCLUSIONS

Eight older large dams, namely Cubuk-1, Golbasi, Gebere, Sihke, Porsuk-1, Sariyar, Kemer and Hirfanli, were considered for seismic hazard and total risk in this study. The dams considered for this study have been located at different places throughout country. Some of the dams, which were located near active seismic zone, can be damaged or failed during earthquakes. The PGA values range from 0.252g to 0.434g (moderate to extreme hazard classes) for these critical dams. These dams cannot meet current standards of seismic design. They will be under near-field motion during earthquake. Therefore, their seismic upgrade should be provided soon. Especially, Kemer dam is the most critical dam in Great Menderes basin when considered public safety for downstream life. Sariyar and Porsuk dams also have high risk for downstream life and properties. For each dam, a special safety program should be developed and analytical and numerical analyses should be performed by means of new approximations on dam engineering to relieve excessive deformations such as slumping, settlement, cracking and planar or rotational slope failures for embankment dams. Concrete aging seems another problem for rigid structures.

REFERENCES

Ambraseys, NN (1995). *The Prediction of Earthquake Peak Ground Acceleration in Europe*. Earthquake Engineering and Structural Dynamics, V.24, 467-490.

Boore, DM, Joyner, WB. and Fumal, TE (1993). *Estimation of response spectra and peak accelerations from Western North American earthquakes*. An interim report. Open file report 93-509.U.S.G.S.

Boore, DM., Joyner, WB. & Fumal, TE. 1997. *Equation for Estimating Horizontal Response Spectra and Peak Acceleration from Western North American Earthquakes.* A Summary of recent Work. Seismological Research Letters, V.68, N.1, January /February, 128-153.

Bureau, GJ. 2003. *Dams and Appurtenant Facilities in Earthquake Engineering Handbook edited by Chenh, W.F and Scawthorn,C.* CRS press, Bora Raton 26.1-26.47.

Campbell, KW. 1981. N*ear-Source Attenuation of Peak Horizontal Acceleration*: Bulletin Seism. Soc. Am., V.71, N.6, 2039-2070.

DSİ. 2012. *Selection of Seismic Parameters for Dam Design.* State Hydraulic Works, Ankara, 29 p (in Turkish).

FEMA.2005. *Federal Guidelines for Dam Safety—Earthquake Analyses and Design of Dams*.

Fraser, WA & Howard, JK. 2002. *Guidelines for Use of the Consequence-Hazard matrix and Selection of Ground Motion Parameters:* Technical Publication, Department of Water Resources, Division of Safety of Dams.

ICOLD. 1989. *Selecting Parameters for Large Dams-Guidelines and Recommendations*. ICOLD Committee on Seismic Aspects of Large Dams, Bulletin 72.

ICOLD. 2016. *Selecting Seismic Parameters for Large Dams-Guidelines*. ICOLD, Bulletin 148.

Jansen, R.B (Ed.). 1988. Advanced Dam Engineering for Design Construction and Rehabilitation, Van N. Reinhold, New York 884 pp.

Jiminez, MJ, Giardini, D & Grünthal, G. 2001. *Unified Seismic Hazard Modelling throughout the Mediterranean Region.* Bolettino di Geofisica Teorica ed Applicata, Vol.42, N.1-2, Mar-Jun., 3-18.

Kalkan, E & Gülkan, P.2004. Site-Dependent Spectra Derived from Ground Motion Records in Turkey, Earthquake Spectra, 20, 4, 1111-1138.

Kramer, SL. 1996. *Geotechnical Earthquake Engineering:* Prentice-Hall, Upper Saddle River, NJ 653 p.

Krinitzsky, E. 2005. Discussion on Problems in the Application of the SSHAC Probability Method for Assessing Earthquake Hazards at Swiss nuclear power plants. Eng. Geol. 78 285-307; Eng.Geo. 82, 62-68.

MTA. 2013. Scale 1/1.125.000 Turkey Live Fault Map. General Directorate of Mineral Research and Exploration. Special publications series, Ankara, Turkey.

Tosun, H. 2002. *Earthquake-Resistant Design for Embankment Dams*: Publication of General Directorate of State Hydraulic Works, Ankara. 208 pp. (in Turkish).

Tosun, H., Tosun, V.T. Onder, T.B. and Usul, H. 2019. *Total Risk and Seismıc Hazard of Large Dams in the Main Basin of West Anatolia, Turkey.* 11th ICOLD European Club Symposium, 2-4 October, Chania, Crete.