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SEISMIC HAZARD AND TOTAL RISK ANALYSES OF CONCRETE-FACED ROCKFILL DAMS IN TURKEY

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ABSTRACT

Large dams, which are constructed near urban areas, have a high risk potential for downstream life and property. The total risk for dam structures mainly depends on the seismic hazard rating of dam site and the risk rating of the dam and appurtenant structures. Turkey, which has at least 1200 large dams, is one of the most seismically active regions in the world and major earthquakes with the potential of threading life and property occur frequently here. The concrete-faced rockfill dam (CFRD) is now one of the most popular types of dam in Turkey. This paper discusses guidelines for the selection of parameter to be used in the seismic design and safety evaluation of dams and briefly introduces the analyses performed for six concrete-faced rockfill dams, which are now under construction or operation stages.

Keywords: CFRD, dam, seismic hazard, total risk

INTRODUCTION

The concrete-faced rockfill dam has been constructed with increasing frequency in last decade, because of no settlement problems through the use of compacted rockfill. It is believed that the entire rockfill mass increases the overall stability of dam, since the water pressure acts on the upstream face. It is advantagely regarded that there can be no pore water pressure due to earthquake shaking, because the embankment does not include water inside. Therefore, it is not necessary to consider a strength reduction for embankment materials. They have a high resistance to seismic loading when well compacted.

In the world, its construction was started for moderate height in 1940, but developed fast in 1970's with the application of vibratory roller. The progress of this type of dam was very fast in South America and Australia. Significant advances in the design and construction of dams have been observed nowadays. Especially, the Australian practice on CFRD is very rich, because there are so many examples with different problems in this country (Fitzpatrick et al., 1985). Brazil also poses valuable experience on CFRDs. Foz de Areia, Xingo and Segredo dams are the important structures in this country. Shuibuya dam in China, which has 232 m height, will be the highest CFRD in the world when completed. Bakun dam in Malaysia, which is the world's second highest CFRD, is expected to complete in 2007.

For concrete faced rockfill dam, design and construction seem very simple, when compared with other types of embankment dam. It is generally designed on the basis of previous experience. In some cases, the leakage problems were observed and resulted to remedial measures. Therefore, the authors point out the fact that it is necessary to have more attention about plinth construction, foundation

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preparation, rockfill selection and placement, upstream face control, handling of waterstops and upstream face construction by slipforming. Durability of concrete face slab is important factor acting on long-term behavior of this type (Yoon et al., 2002).

The time-dependent deformation, especially separation between concrete face slab and cushion layer, seems one of the most significant problems of high concrete-faced rockfill dams (Zhang et al, 2004). Therefore, selection of rockfill material should be made with care to prevent unpredicted settlement during water impounding. Well-graded rockfill or gravel (with free drainage) is commonly adopted as an excellent material in practice of the developed countries. Some design engineers state that weathered rockfill or dirty gravel can also be used, if zoning is taken into account and compaction for rockfill material is well provided. Its settlement behavior is largely dependable on deformability characteristics of embankment materials (Tosun et al., 2006). Bouzaiene (2006) states that leakage problem in the CFRDs is usually attributed to the development of tensile cracks in concrete face slabs.

Dam engineers consider the fact that well-compacted CFRD has a high resistance to earthquake loading. Bureau et al (1985) state that this thought is based on several factors including acceptable past performance of similar dams, a recognition that the entire embankment is unsaturated and the fact that compacted rockfill develops high frictional resistance. Intensive investigations have been performed to explain their behavior under dynamic loading. Uddin (1999) introduces a dynamic analysis procedure for concrete-faced rockfill dams subjected to strong seismic excitation. Numerical solutions performed for CFRD indicates that it is safe as well as other embankment dams. However, their behavior is questionable, when they are subjected to seismic loading, which is caused by near energy zone.

EXPERIENCE ON CFRD IN TURKEY

The construction of concrete-faced rockfill dam has been started in 1997 in Turkey, although it is a common-used type in the world since 1940. However, the concrete-faced rockfill dam has been used with increasing frequency in recent years in Turkey. Six concrete-faced rockfill dams ranging in height from 74 to 152 m have been designed and constructed since 1997 (Table 1). Two of them were entirely completed in 2003 and 2005, while four of them are now under construction. Three of them, namely Kurtun dam, Atasu dam and Torul dam are constructed within the same basin at the northern part of Turkey. Gordes and Marmaris dams are constructed for water supply and irrigation purpose at west, while the last one is located at south with multi purpose such as water supply, irrigation, flood control and electricity. Further studies at least 25 dams of this type are in early stage of design in Turkey. In 2005 new quidelines for designing the concrete-faced rockfill dams were acted in Turkey.

Table 1. The concrete-faced rockfill dams in Turkey

Dam	Purpose*	Height from foundation (m)	Completed year**	Volume of embankment (hm^3)	Reservoir capacity (hm^3)	Irrigation area (ha)
Atasu	WS+E	122.0	U/C	3.8	35.7	-
Dim	WS+I+FC+E	134.5	U/C	4.1	250.6	5312
Gordes	I+WS	94.9	U/C	5.5	448.5	14423
Kurtun	E	133.0	2003	3.0	108.2	-
Marmaris	I+WS	74.0	2005	1.3	-	-
Torul	E	152.0	U/C	4.6	168	-

(*) WS = Water supply E = Energy I= Irrigation FC = Flood control
(**) U/C = Under consruction

Kurtun dam, which impounds 108.2 hm^3 of water at maximum water level, is the first concrete-faced rockfill dam of Turkey. It has 133 m high from foundation and 300 m long on crest. It was originally designed as a rockfill dam with central core. However, its type was revised to concrete-faced rockfill type, as a result of intensive geotechnical studies. Intrusive volcanic rocks, regarded as an appropriate rock for dam foundation, form the basement of Kurtun dam. The crest width is 14 m and the side slopes of main embankment are 1.4H: 1V for upstream and 1.5H: 1V for downstream. It produces 198 GWh per year with an installed capacity of 80 MW.

Torul dam, located 5 km east of the reservoir of Kurtun dam in the northern portion of Turkey, is a concrete-faced rockfill dam on the Harsit River. It has a 152 m height form foundation. When the reservoir is at normal capacity, the facility impounds 168 hm^3 of water with a reservoir surface area of 3.86 km^2. Its construction was started in 2000 and is expected to entirely finish in 2007. It was designed to produce electricity of 322 GWh per year with an installed capacity of 103 MW. The main embankment consists of four major zones. The impervious section of the embankment is a concrete slab and plinth structure on upstream. The main elements of embankment are large-sized crushed rocks at which the most durable and high strengthen ones are located on the outer part of the shell.

Atasu dam is a concrete-faced rockfill dam 122 m high, with a total embankment volume of 3.8 hm^3. It is located 17 km southeast of the Macka County and designed as a multi-purpose dam for providing water supply of Trabzon city and producing electricity. When it is completed, it will produce electricity of 150 GWh per year with an installed capacity of 45 MW. Its construction was started in 1998 and will be finished in 2007. When the reservoir is at operation stage with normal water level, the facility approximately impounds 35.7 hm^3 of water with a reservoir surface area of 0.83 km^2. The upstream and downstream shells are composed of large-sized crushed rocks. A 6-m thick alluvium, which is composed of sand, gravel, clay and silt mixtures, was entirely removed before beginning to the construction of main embankment. Thus, the dam was based on good quality bedrock.

Gordes dam is also constructed as a concrete-faced rockfill dam on Gordes River at the western portion of Turkey. It is a multi-purpose dam for proving drinkable water of Manisa city and irrigating an area of 14423 ha. Its height from riverbed and foundation is 82.9 m and 94.9 m, respectively. It has the largest capacity of concrete-faced rockfill dams in Turkey. When the reservoir is at normal capacity, the facility impounds 448.5 hm^3 of water with a reservoir surface area of 14.05 km^2. Its construction was started in 1998 and will be completed in 2007.

Dim dam is designed as a multi-purpose structure to be built at the southern part of Turkey. It is also a concrete faced rockfill dam with 123.5 m height from riverbed. When the reservoir is at operation stage with normal water level, the facility approximately impounds 250.6 hm^3 of water with a reservoir surface area of 4.7 km^2. The upstream and downstream shells are composed of large-sized crushed rocks. The embankment was founded on good quality bedrock. It is expected to finish in 2007, although it is the first concrete faced rockfill dam, which was started in Turkey.

Marmaris Dam is the first concrete-faced rockfill dam of country, which was constructed by a municipality with international finance model. It provides drinkable water for Marmaris city and its vicinity, which is one of most fantastic area for tourism sector. It has a 74 m height from foundation. It was planned to supply water for the region up to 2040.

METHODS OF ANALYSIS

For the seismic hazard analysis of a particular site, all possible seismic sources are identified and their potential is evaluated in detail, as based on the guidelines given by Fraser and Howard (2002) and the unified seismic hazard modeling for Mediterranean region introduced by Jiminez et al., (2001). The study of seismic activity includes 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 evaluation of the worst ground motions. 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 the uncertainties can be identified and combined in a rational manner to provide a more complete picture of the seismic hazard.

The seismic hazard parameters were estimated by using the method developed by Gumbel and the Gutenberg-Richter methods. The Operating Basis Earthquake (OBE) was defined by means of the probabilistic methods mentioned above. It 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. Maximum Credible Earthquake (MCE), which is the largest earthquake magnitude that could occur along a recognized fault or within a particular seismotectonic province or source area under the current tectonic framework, was obtained for each zone and the most critical one for the dam site was selected as Controlling Maximum Credible Earthquake (CMCE) and then Maximum Design Earthquake (MDE) was defined. FEMA (2005) states that MDE is normally characterized by a level of motion equal to that expected at the dam site from the occurrence of deterministically evaluated MCE. Most of large dams in Turkey were analyzed as using these definition (Tosun and Seyrek, 2005; Tosun and Savas, 2005).

There are various methods to quantify the total risk factor of a dam. One of them as 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, 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.

ICOLD (1989) states that potential risk of dams consists of structural components and social-economics components. The first one is mainly based on the capacity of the reservoir and the height of dam. The second one can be expressed by the evacuation requirement and potential downstream damage. The total risk factor is defined as a summation of risk factors for capacity, height, evacuation requirements and potential damage. Based on the total risk factor, four risk classes are defined as low, moderate, high or extreme. Risk classification of a dam provides more detailed information for the selection of seismic evaluation parameters and methods to be used for analysis. It should be noted that special considerations for safety are recommended for large dams having a height above 90 m and a storage capacity greater than 1200 hm^3.

A second method to quantify the safety of a dam defines total risk factors, which depend on the dam type, age, size, downstream risk potential and the dam’s vulnerability (Bureau and Ballentine, 2002). The Total Risk Factor (TRF) includes a downstream hazard factor, which has two different components. Bureau (2003) also suggests a simple classification chart for estimating the downstream hazard factor when it is difficult to obtain sensitive values of risk factors for downstream evacuation requirements and downstream damage, respectively.

For obtaining the seismic vulnerability of rating, a curve developed by Bureau and Ballentine (2002) is used. By using this curve, a Predicted Damage Index (PDI) can be obtained. The PDI value depends on the Earthquake Severity Index (ESI). As based on the ESI value, the PDI can be estimated from a graph and then the Predicted Damage Factor (PDF) is calculated. The local magnitude of the causative earthquake and the peak ground acceleration are considered to estimate the seismic vulnerability of dams. The last step for assessment techniques is to rank the dams by TRF and to assign risk classes. Bureau (2003) states that risk class can be used to establish the need for more detailed seismic evaluations and to estimate priorities for such evaluations.

SEISMIC HAZARD AND TOTAL RISK ANALYSES

The total risk for dam structures mainly depends on two factors: (1) the seismic hazard rating of dam site and (2) the risk rating of the dam and appurtenant 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. 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 (ICOLD, 1989). Recently, these two factors were combined to define the total risk factor for dam structure (Bureau, 2003).

The seismic sources were identified and the recurrence interval of earthquakes was estimated. As a result of an extensive survey and a search of available literature, several sources have been identified to help analyze the seismic hazard of dams in Turkey (Yucemen, 1982; Erdik et al., 1985; Saroglu et al., 1992). The location of dams on the seismo-tectonic map of Turkey is given in Figure 1. The data about historical and 20th century instrumentally recorded earthquakes for Turkey and vicinity collected by the National Disaster Organization was considered as a basis for the seismic hazard analyses. The earthquakes that occurred within the last 100 years were used for estimating seismic parameters. Due to the unavailability of strong motion records, various attenuation relationships were adopted (Ambraseys, 1995; Campbell, 1981) to calculate the peak ground acceleration (PGA) acting on dam sites. Throughout the study, seismic zones and earthquakes within the area having a radius of 100 km around the dam site were considered. For all analyses, the peak ground acceleration was deterministically determined by considering the Maximum Credible Earthquake (MCE). All procedures mentioned above can be executed by the DAMHA program, developed at the Earthquake Research Center of Osmangazi University-Turkey, that is working on the basis of geographic information system (GIS).

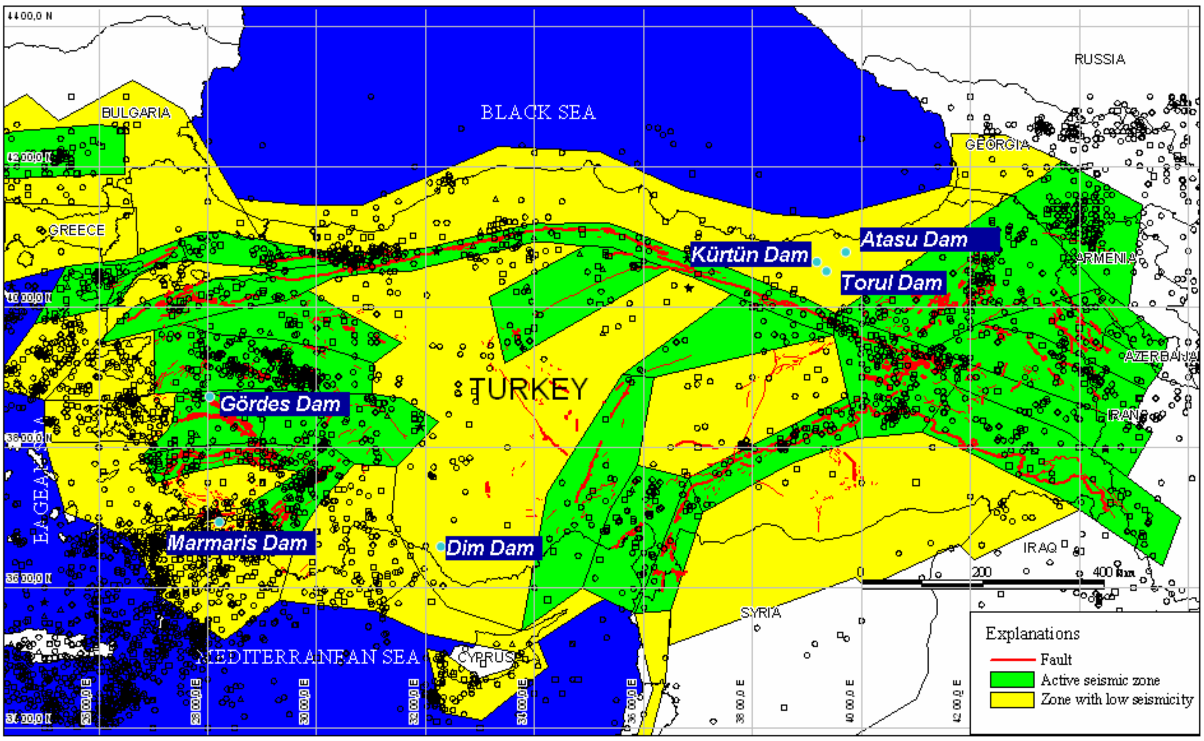

Figure 1. Location of dams on the seismo-tectonic map of Turkey

For the study, six CFRDs, located in different seismic zones were considered. The PGA and TRF values with risk classes obtained from seismic hazard and potential risk analyses by means of the program mentioned above are given in Table 2 for all dams. Two of them are very close to the energy source, while others are located on sites with low seismicity. The summary outputs of seismic hazard analyses for Marmaris and Gordes dams are given in Figure 2 and 3, respectively. The PGA values range from 0.01g to 0.20g. According to ICOLD classification, one of them will be subjected to moderate hazard rating. The others are identified as low hazard ratings (Table 3).

Table 2. PGA and TRF values of dams considered in this study

Dam	PGA in g *	M_L **	TRF ***	Risk class
Atasu	0.05	5.3	50.3	II
Dim	0.01	5.4	33.8	II
Gordes	0.09	6.7	121.0	II
Kurtun	0.03	6.2	86.9	II
Marmaris	0.20	6.7	129.1	III
Torul	0.07	7.9	140.4	III

(*) PGA =Peak ground acceleration
(**) M_L =Local magnitude of the earthquake
(***) TRF=Total risk factor

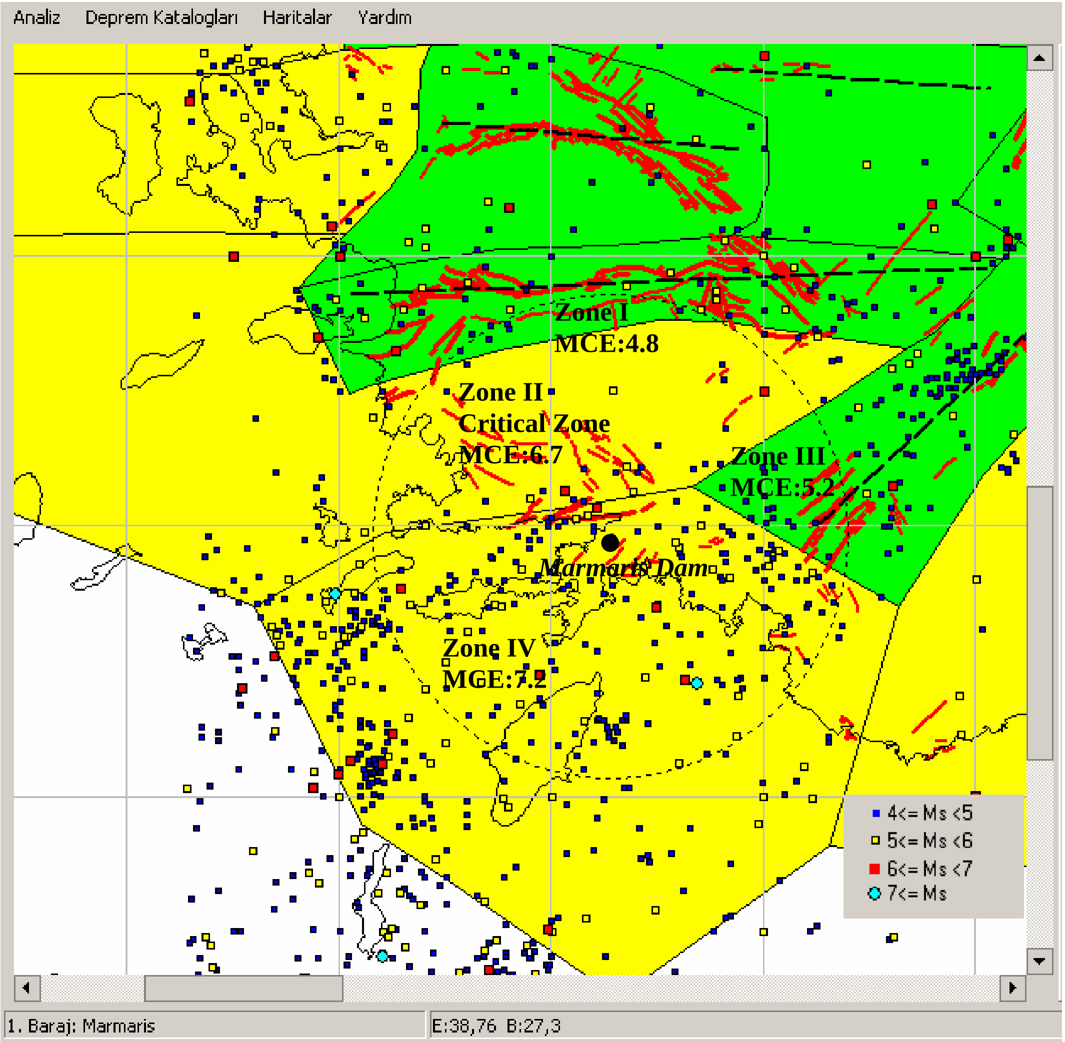

Figure 2.The summary output of seismic hazard analyses for Marmaris dam

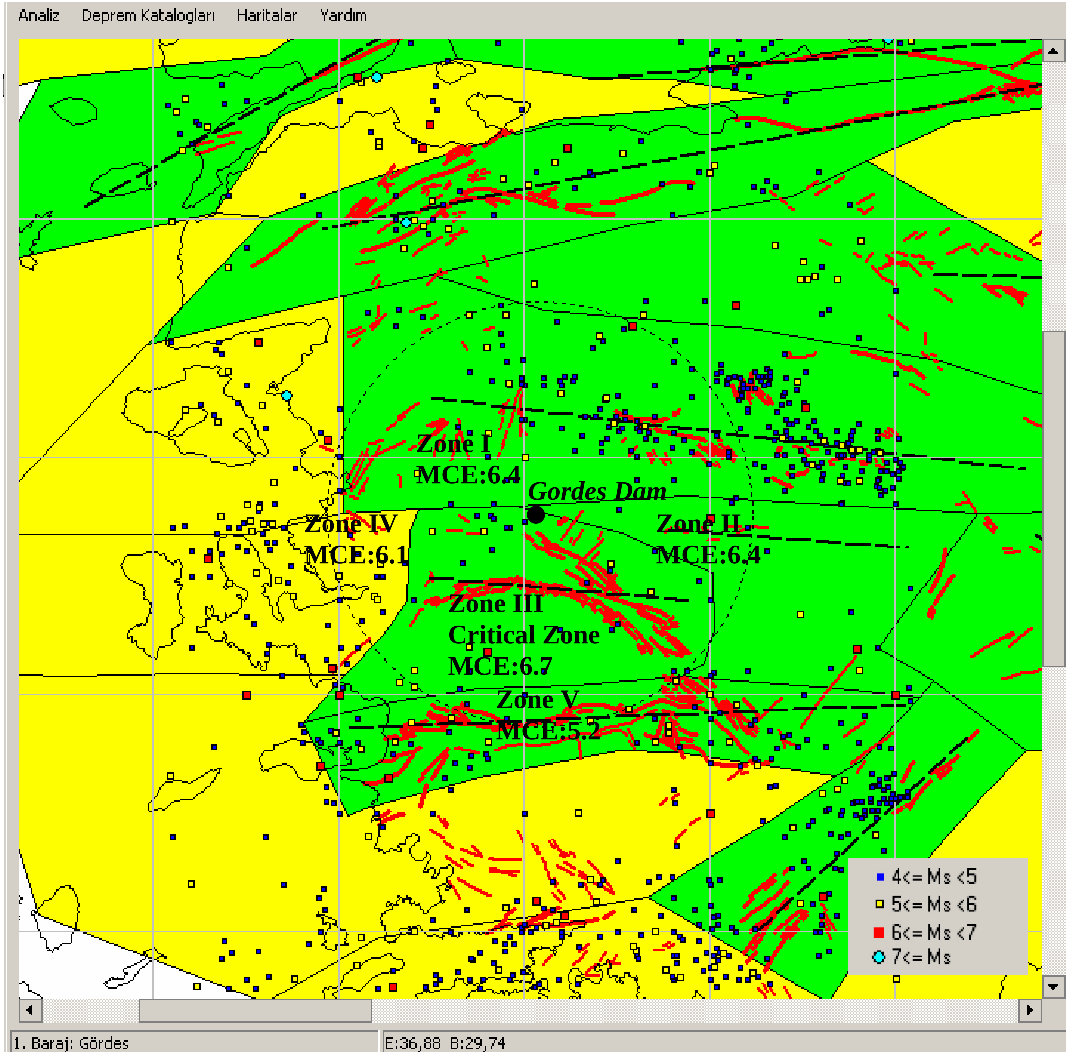

Figure 3.The summary output of seismic hazard analyses for Gordes dam

Table 3. Hazard class of dams considered in this study

Dam	PGA in g *	M_L **	Hazard class
Atasu	0.05	5.3	I
Dim	0.01	5.4	I
Gordes	0.09	6.7	I
Kurtun	0.03	6.2	I
Marmaris	0.20	6.7	II
Torul	0.07	7.9	I

(*) PGA =Peak ground acceleration
(**) M_L = Local magnitude of the earthquake

Kurtun, Atasu ve Torul dams are very close to each other and located in the same energy source (Figure 1). For three dams following results were obtained as based on seismic hazard and potential risk analyses:

- Kurtun dam is not located on active seismic region and also its Total Risk Factor (TRF) value is not high. Therefore, it is identified as risk class of II. This dam site is in excellent condition, but landslides on reservoir area seem as problem for overall stability of project.

- Atasu dam is not one of the critical dams within the basin. It will be subjected to a peak ground acceleration of 0.05g with a M_L of 5.3. Table 2 indicates that it seems safe for earthquake conditions. It is identified as class II with moderate risk.

- Torul dam will be subjected to a peak ground acceleration of 0.07g with a M_L of 7.9 and it is not close to the energy source (Table 2). The TRF value is high, even if it is located in an area with low seismic activity. Because its structural impact on the TRF value is very high.

Dim dam, which is located at south part of country, will be subjected to a peak ground acceleration of 0.01g with a M_L of 5.4 (Table 2). Its location has very low seismic activity. It is identified as class II with moderate risk. There can be leakage problem for foundation in long-term for this structure.

There two separate dams under the influence of near energy zone in western Turkey. One of them is Marmaris dam that is located on an active seismic zone. Its Peak Ground Acceleration (PGA) and Total Risk Factor (TRF) values, obtained from a detail seismic hazard and potential risk analyses, are 0.20g and 129.1, respectively. It is identified as risk class of III. The other one is Gordes dam which is located on a shear zone. Its TRF value is 121.0 and it is identified as risk class of II. It will be subjected to a peak ground acceleration of 0.09g with a M_L of 6.7 (Table 2).

CONCLUSIONS

Following conclusions can be drawn from this study:

- The main requirement of an earthquake –resistant design of a dam is to protect public safety and property. Therefore, seismic criteria and analyses parameters for dams should be selected more conservatively than for conventional structures since the failures are more disastrous.
- The seismic hazard analyses performed on the CFRDs in Turkey indicates that all dams with except of Marmaris dam is not critical structure. Their hazard ratings are low (hazard class:I). Marmaris dam is identified in hazard class II and its rating is moderate.
- As based on potential risk analyses, Torul and Marmaris dams are the most critical structures. Their TRF values are greater than 125 and they are classified into risk class III with high risk. The rest are classified as risk class II.
- For the dams with high risk rating, detail further analyses should be considered with the acceleration time histories.

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