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Table of Contents: Volume 10   Number 2   August 2018

ARTICLES

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Full Length Research Paper

Comparative evaluation of short and long term *in vitro* antibacterial activity of white and gray mineral trioxide aggregate and calcium enriched mixture cement"

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The aim of this study was to investigate and compare the short and long term antibacterial effects of white and gray mineral trioxide aggregate (MTA) and calcium enriched mixture (CEM) on Streptococcus Sanguinis and Enterococcus faecalis which are commonly associated with endodontic infections. The test materials, including white MTA (WMTA), gray (GMTA), and CEM were manipulated strictly in accordance with the manufacturer's instructions. A total of 72 culture plates were prepared and divided into three experimental groups (one group for each of freshly mixed and set WMTA cements; one group for each of freshly mixed and set GMTA cements; one group for each of freshly mixed and set CEM cements. Each group consisted of 24 plates in which 12 plates were cultured by S. sanguinis and the other 12 plates were cultured by E. faecalis. Antibacterial activities of the materials against the S. sanguinis and E. faecalis were evaluated using agar diffusion test (ADT). The materials were tested in form of set (24-h, 1 week and 1 month) and freshly mixed. In the E. faecalis groups, plates containing freshly mixed and set WMTA, GMTA, and CEM cements did not show any antibacterial properties. The antimicrobial activity of freshly mixed GMTA was lower than WMTA and higher that of CEM. The largest mean diameters of inhibition zone of bacterial growth were found in set WMTA cement group at any time period. In conclusion, the origin of MTA as well as the preparation techniques may affect its antimicrobial activities.

Key words: White mineral trioxide aggregate (WMTA), gray mineral trioxide aggregate (GMTA), calcium enriched mixture (CEM), growth inhibition zone, *S. sanguinis,* antibacterial activity, agar diffusion test, *E. faecalis.*

INTRODUCTION

Microorganisms and their byproducts are the main etiologic factors for the development and progression of pulpal and periapical disease as well as in endodontic treatment failures (Fouad et al., 2005). Most endodontic treatment failures are attributable to inadequate cleansing of the RC and egress of bacteria and other antigens into

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the periradicular tissues (Hasan Zarrabi et al., 2009).

Elimination of microbial flora and infected tissues during root canal (RC) treatment by instrumentation, irrigation and intracanal medication has always been an important part of successful endodontic treatments (Sundqvist, 1982). After a RC procedure, because of persistence of inflammation or infection in the bony area around the end of the tooth, then it is necessary to perform an apicoectomy and a root-end filling is placed to prevent re-infection of the root (Bhavana et al., 2015).

Endodontic treatment result will depend on the effective seal to prevent future recontamination as well as successful reduction or elimination of the associated microorganisms (Torabinejad et al., 1995). Antimicrobial testing of biomaterials should consider this effect. The agar-diffusion test (ADT) is the most commonly used technique for evaluating antibacterial property of dental materials (Cobankara et al., 2004). Hence, root-end filling materials not only should have sealing ability and biocompatibility but also should ideally have some antibacterial activity to prevent bacterial and fungal growth (Hasan Zarrabi et al., 2009). However, numerous materials have been recommended as root-end filling materials; none has so far been found to be completely ideal. One of the well-known root-end filling materials is mineral trioxide aggregate (MTA), which has unique properties such as, excellent sealing ability, high alkalinity induction of hard tissue formation, and antibacterial effects (Bhavana et al., 2015; Tziafas et al., 2002). Due to its physical and chemical properties, the use of MTA as a biomaterial for a wide variety of endodontic treatments has been recommended (Torabinejad and Chivian, 1999). In a recent prospective clinical study, MTA showed a high success rate when used as root-end filling material (Saunders, 2008). However, MTA has a delayed setting time and poor handling characteristics, and is expensive to use (Asgary and Kamrani, 2008).

Recently, calcium enriched mixture (CEM) cement, also called new endodontic cement (NEC), has been developed with similar clinical uses to tooth-colored ProRoot MTA but different chemical composition (Asgary et al., 2008). It mainly contains different calcium compounds.

This material has acceptable physical properties and is capable of hydroxyapatite formation over material in normal saline solution (Asgary et al., 2008a). An experimental study carried out on dogs demonstrated that MTA and NEC have the same favorable results as pulp capping materials and were even preferred over calcium hydroxide (Asgary et al., 2008c). This biocompatible cement forms an effective seal when used as root-end filling material and the results is comparable with different root-end filling materials (Asgary et al., 2008a).

In recent years, several studies have been carried out on the antibacterial characteristics of MTA (Bhavana et al., 2015; Asgary et al., 2006); less research has been performed on the antibacterial properties of CEM (Asgary et al., 2007). Moreover, antibacterial properties of root-end filling materials have been rarely compared. Based on data gathered from previous studies, long term antibacterial effects of the materials have been not considered before. Therefore, the aim of this study was to investigate and compare the long term antibacterial effects of white and gray MTA and CEM on *Streptococcus Sanguinis* and *Enterococcus faecalis* microorganisms which are commonly associated with endodontic infections using the agar diffusion test (ADT).

MATERIALS AND METHODS

The test materials, including WMTA (Angelus, Londrina, Paraná, Brazil), GMTA (Angelus, Londrina, Paraná, Brazil), and CEM (ShahidBeheshti University of Medical Sciences, Iran) were manipulated strictly in accordance with the manufacturer's instructions. Antibacterial activities of the materials against *S. sanguinis* and *E. faecalis* were evaluated using ADT. The materials were tested in form of set (24-h, 1 week and 1 month) and freshly mixed. A total of 72 culture plates were prepared and divided into three experimental groups (one group for each of freshly mixed and set WMTA cements; one group for each of freshly mixed and set GMTA cements; one group for each of freshly mixed and set CEM cements. Each group consisted of 24 plates in which 12 plates were cultured by *S. sanguinis* and the other 12 plates were cultured by *E. faecalis*.

Agar diffusion test

The study was conducted on double-layer plates, in which the base layer was made of 10 ml Muller-Hinton agar (MHA) (Difco, USA) poured into 100 ml sterilized Petri dishes. Four uniform cavities (5 mm in diameter and deep, one for each test material) were punched at equidistant points in the agar using Pasteur pipette after 24 h. The cavities were immediately filled by materials after being mixed with amalgam carrier.

Lyophilized samples of *S. sanguinis*(PTCC 1449) and *E. faecalis* (PTCC 1394) were provided by Industrial and Scientific Research Organization, Tehran, Iran. The bacteria were dissolved in 0.5 ml Brain-Heart Infusion (Himedia, India) and cultured on the surface of Nutrient agar (Himedia, India) using sterile cotton swabs. Microbial strains were confirmed by gram staining and colony and biochemical properties. Fresh inoculate of each microorganism was prepared by growing an overnight culture until a complete suspension of growth was achieved. Both bacteria strains were diluted to obtain a suspension of approximately 5×10^8 colony forming unit/ml (0.5 in McFarland nephelometer) in sterile Trypticase Soy Browth (TSB). *S. sanguinis* and *E. faecalis* suspensions were inoculated with sterile cotton swabs onto MHA (Difco, USA) plates (Asgary et al., 2008a). After pre-diffusion of the three test materials for 2 h at room temperature, all experimental groups were then incubated at 37°C. Antibacterial properties of the materials were evaluated immediately after the insertion of set (24-h, 1 week and 1 month time periods) and freshly mixed material test. To set the test material, all the materials were poured into the cavities of sterile media and were kept closed at 4°C until the experiment. Round of the plates were covered with para-film to prevent evaporation.

Table. 1. The antibacterial activity of test materials toward *S. sanguinis*. The zones of growth inhibition presented in millimeters.

Forms /Material	WMTA	GMTA	CEM	P value
Freshly mixed	28.83±0.76	23.66±0.57	19.66± 0.57	0.02
24-h set	27.83±0.28	23.83±0.28	19.66±0.57	0.025
1 week set	23.66±0.57	20.66±0.57	18.66±1.15	0.029
1 month set	21.66±0.57	18.66±1.15	14.16±0.28	0.025

Microbial inhibition zones were measured blind using a 0.5 mm precision ruler.

Statistical analysis

To compare the differences among WMTA, GMTA, and CEM; data were analyzed statistically by one-way analysis of variance (ANOVA) and Tukey's honest significant difference (HSD) post-hoc test, using Statistical Package for Social Sciences (SPSS) software version 21. *P* value < 0.05 was considered as statistically significant. Intra-group differences were analyzed by using repeated measure ANOVA.

RESULTS

In the *E. faecalis* groups, plates containing freshly mixed and set WMTA, GMTA, and CEM (24-h, 1 week and 1 month) cements did not show any antibacterial properties.

The antibacterial activities of set and freshly mixed test materials determined by the means and standard deviation of growth inhibition zones in millimeters on *S. sanguinis* are presented in Table 1. The data obtained from the freshly mixed cements revealed that the mean growth inhibition zones of WMTA on *S. sanguinis* was larger in diameter than that of the CEM and GMTA. Freshly mixed GMTA group was associated with smaller growth inhibition zones compared to the WMTA group (Table 1). However, no significant difference was observed in the mean growth inhibition zones of the two groups (P=0.12).

Growth inhibition zones in freshly mixed CEM group was significantly smaller than that of WMTA and GMTA (*P*= 0.02) (Figure 1).

The largest mean diameters of inhibition zones of bacterial growth were found in set WMTA cement group at any time period.

The differences between inhibition zones of bacterial growth of the set CEM cement were significant compared to the GMTA and WMTA (24h, *P*= 0.025; 1week, *P*= 0.029; 1 month, *P*=0.025). Set GMTA group was associated with smaller growth inhibition zones compared to that in the WMTA group at any time period (24 h, 1 week, and 1 month) (Table 1). However, no significant

difference was observed in the mean growth inhibition zone of the two groups (P=0.28).

The mean values of growth inhibition zones of WMTA on *S*. sanguinis were 28.83, 27.83, 23.66, and 21.66 mm when freshly mixed, 24-h, 1 week and 1 month set were used respectively. Increasing the incubation time of the mixed cements resulted in a reduced mean growth inhibition zones in WMTA group. The reduction of the growth inhibition zones was statistically significant in 1 month set WMTA compared to the freshly mixed (*P*<0.001) and 24-h set WMTA (*P*= 0.04) (Table and Figure 1).

Similar with what was observed in WMTA group, increasing the incubation time of the mixed cements resulted in a decrease in the mean growth inhibition zones in GMTA and CEM groups. The mean growth inhibition zones of 1 month set GMTA cement was significantly different compared to the freshly mixed GMTA (*P*= 0.02) and 24-h set GMTA (*P*= 0.01). The data obtained from changing the incubation time of the CEM cements were similar to those of WMTA and GMTA. The smallest mean growth inhibition zones were seen in 1 month set CEM group. The differences between the mean inhibition zones were statistically significant in 1 month set CEM group compared to the freshly mixed (*P*= 0.02) and 24-h set CEM cement (*P*= 0.02).

DISCUSSION

The primarily aim of this study was to evaluate and compare the antibacterial properties of freshly mixed and set WMTA, GMTA, and CEM cements. Based on our knowledge, this is the first study that investigates the more than one month antibacterial effects of white and gray MTA and CEM on *S. sanguinis* and *E.* faecalis microorganisms using ADT. Agar diffusion test is the most frequently used method for evaluating *in-vitro* antibacterial activity of root-end filling materials (Nirupama et al., 2014). This test indicates which materials are more likely to have antibacterial activity within the root canal system via direct comparisons between them (Siqueira et al., 2000). It has been previously demonstrated that the selected bacteria in
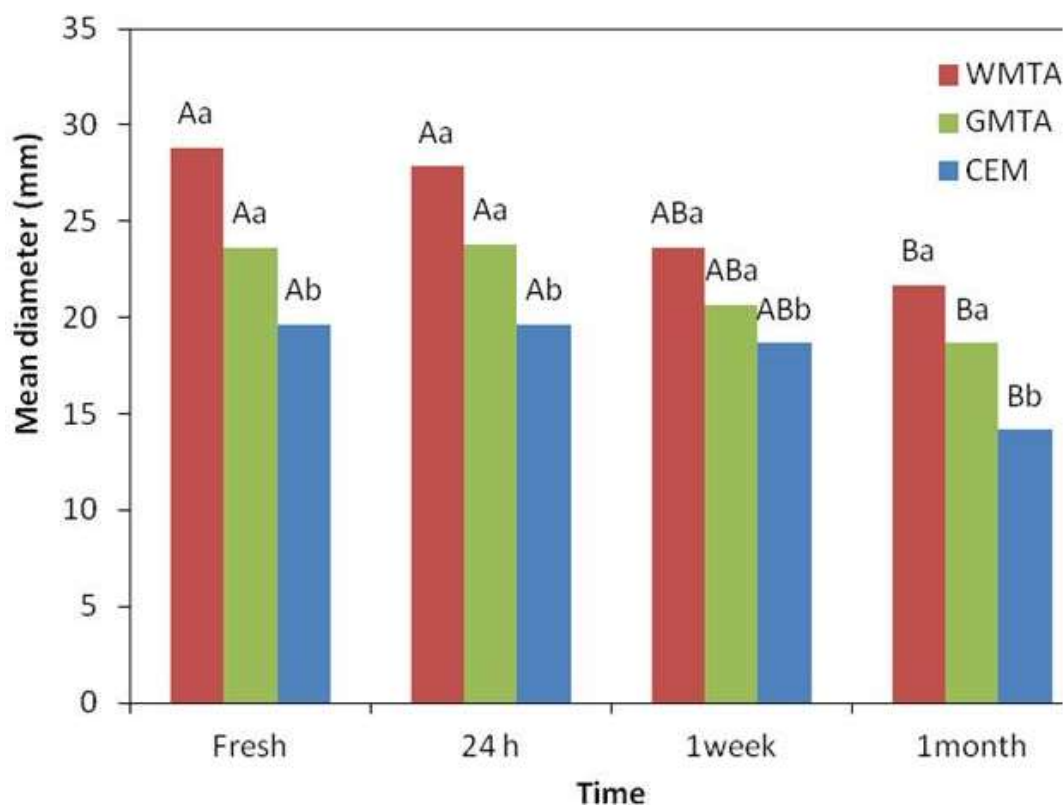
Figure 1. The mean growth inhibition zones of freshly mixed and set test materials against *S. sanguinis*. Different capital letters represent significant difference in growth inhibition zones of a test material at various time at *P*<.05. Different lowercase letters represent significant difference in growth inhibition zones of various test materials at same time (*P*<.05.).

this study, *S. sanguinis* and *E. faecalis*, are frequently associated with endodontic infections or therapy resistant cases (Sundqvist, 1982). In addition, *E. faecalis* is associated with persistent periradicular lesions after root canal treatment (Portenier et al., 2003).

The data obtained from this study showed that all three tested materials either freshly mixed or set cements were ineffective against *E. faecalis*. These results are in accordance with the findings of other studies that MTA and CEM cements did not show any antimicrobial activity against *E. faecalis* (Hasan Zarrabi et al., 2009; Torabinejad et al., 1995). This consideration in agreement with contrast with the findings by Poggio et al. (2017) who found that time had no effect on antibacterial efficacy.

Investigating the antimicrobial activity of the freshly mixed cement showed WMTA cement had the highest antimicrobial activity against *S. sanguinis*. Furthermore, the antimicrobial activity of freshly mixed GMTA was lower than that for WMTA and higher than that of CEM. These findings suggest that the freshly mixed WMTA (Angelus, Londrina, Paraná, Brazil) contains more potent antibacterial inhibitors such as high pH than GMTA

(Angelus, Londrina, Paraná, Brazil) and CEM (ShahidBeheshti, Iran) cements. The antibacterial effect of MTA against the microorganisms has been attributed to its high pH or release of diffusible substrate into growth medium (Asgary et al., 2007).

However, our results showed that the effective antibacterial activity of freshly mixed WMTA and GMTA resulted in greater growth inhibited zones on *S. sanguinis* than CEM. These findings disagree with the previous studies that showed that the effective antibacterial activity of CEM cement was significantly better than that of the MTA group (Hasan Zarrabi et al., 2009; Asgary et al., 2007), when ProRoot MTA was used; MTA-Angelus was utilized in the present study. It has been reported that the pH and calcium ion release values are slightly higher for MTA-Angelus than ProRoot (20). ADT results are widely influenced by the diffusion ability of the material into the medium. In addition, variations in agar medium, bacterial strains, standardization of inoculation density, incubation, diffusion capacity of inhibitory agents, and reading point of the zones of inhibition are factors that affect the results of ADT (Torabinejad et al., 1995). Differences in materials types may explain the possible reason of this

discrepancy.

The data obtained from the set materials showed that the WMTA cement has the highest antimicrobial activity against *S. sanguinis* at any time period followed by GMTA and CEM cements. Different patterns of inhibition of bacterial growth were found for the set WMTA and GMTA. The differences in antibacterial activity may be due to the physico-chemical differences between the GMTA and WMTA. The origin of MTA as well as the preparation technique may affect its antimicrobial activities (Al-Hezaimi, 2009).

The results of this study illustrated that increasing the incubation time (more than 24 h) of the mixed cements resulted in a reduced mean growth inhibition zones in all three groups. The reduction of the growth inhibition zones was statistically significant in 1 month set materials in all groups compared to the freshly mixed and 24-h set cements. Although the long term antibacterial activities of the applied materials in this study is yet to be investigated. The result obtained from the long term antibacterial activity of test materials disagrees with those of previous study reported by Hasan Zarrabi et al. (2009). They found that the antibacterial effect of MTA, new endodontic cement and Portland cement at different concentrations against five different microorganisms is enhanced with incubation time for 72 h (Hasan Zarrabi et al., 2009).

In WMTA group, inadequate setting and frangibility of WMTA pills were observed in agar medium with increased incubation time. The antibacterial activity of WMTA was maintained because of its poor setting and solubility. The difference in antibacterial activity of various materials may be related to the degree of the material setting (Cobankara et al., 2004).

Conclusion

The origin of MTA as well as the preparation techniques may affect its antimicrobial activities. The favored results of *in-vitro* antibacterial activity of WMTA-Angelus cement compared to the GMTA and CEM cement indicate potentiality of applying WMTA cement as an antibacterial agent on *S. sanguinis*. Moreover, increasing the incubation time, more than 24 h, of the mixed cement resulted in a decreased antibacterial activity of root-end filling materials. However, it is necessary to investigate the effect of these materials on the other pathogens which are frequently associated with endodontic infections or therapy resistant cases.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

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Full Length Research Paper

Probabilistic seismic assessment of arch dams in Turkey

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Arch dams are of great importance in the world. In Turkey, there are 1200 existing dams with different types. Arch dams are important due to their economic resource in irrigation and water supply which are significant to the homeland security and the agricultural economy. Researchers have been carrying out various studies on dams and their seismic resistance especially after the earthquakes that occurred in the recent years. Turkey is also located at one of the earthquake-active zones. In 1999, devastating earthquakes hit Turkey causing severe property losses and thousands of lives. Excessive ground deformation caused severe crack to the existing buildings. Therefore, it is important to investigate the seismic safety of the existing dams in Turkey. In this study, probabilistic seismic risk assessment has been carried out for arch dams: Gökçekaya, Oymapinar, Karakaya, Gezende, Sir, Berke, Deriner, Ermenek Dams. For these arch dams, structural resistances have been discussed. In addition, their resistances have been determined through time history analysis with 60 different ground motion data. After time history analyses, fragility analyses for arch dams have been carried out. The fragility analysis has been used to determine probability of exceedance. Via fragility analyses, level of risk and probability of exceedance have been determined. The exceedance probabilities of the yield and collapse limit states for arch dams in Turkey have been obtained for a realistic probabilistic determination. According to the results, the role of probabilistic seismic risk assessment in dam safety decisions is addressed in detail.

Key words: Arch dams, probabilistic seismic assessment, structural assessment, time history analysis, fragility analysis.

INTRODUCTION

Arch dams are of great importance in Turkey and also in the world due to their economic values in irrigation and water supply which are critical for the homeland security and the agricultural economy. Numerous researches have been conducted on dams and their seismic resistance especially after the earthquakes occurrences of the recent years. It became more important after the earthquakes in 1964 in Alaska and 1971 in San Fernando.

There are various valuable research works available in

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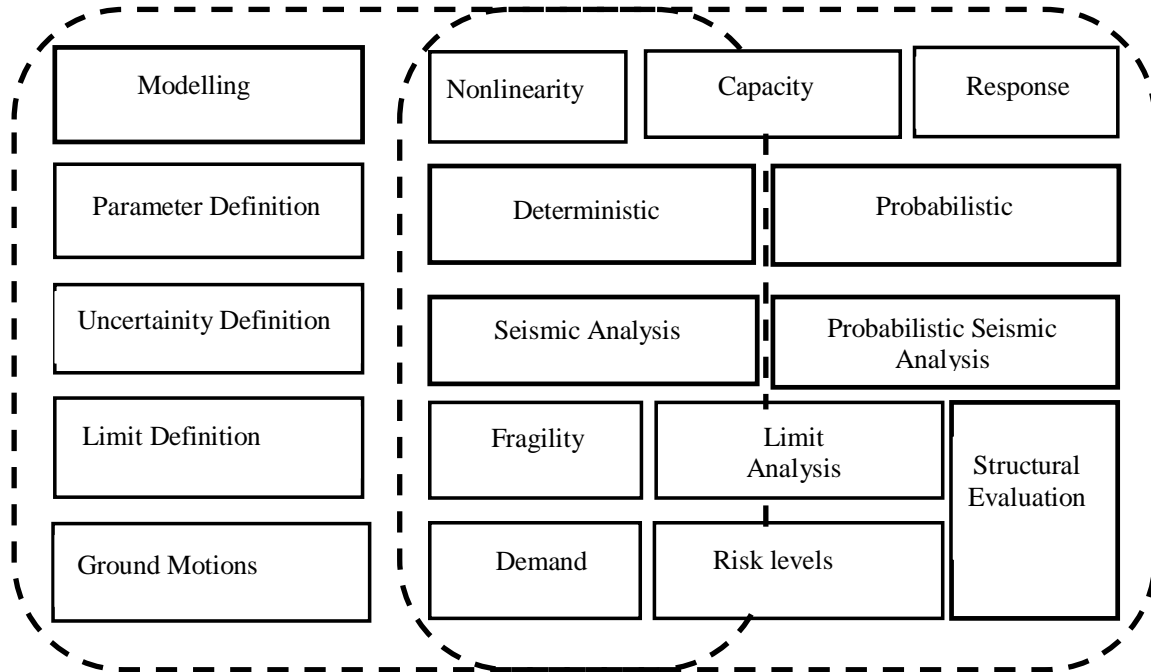
**Figure 1.** Schematic representation of the elements of the seismic risk analysis.

the literature. The dissemination of risk analysis procedures in dam engineering and the interest of scientific community began in the 1990s, even if the first risk analyses were conducted in the 1970s (Pimenta, 2013). Leclerc et al. (2003) conducted the static and seismic analysis of different load conditions using various fracture criteria and uplifting pressures of dams. Zhang et al. (2001) carried out the static and stability analyses of dams using rigid-spring element method and found static and dynamic factor of safety of dam slopes. The other important research works on structural assessment of existing dams are done by Turkman (1991), Yu et al. (2005), Calayir and Karaton (2005), Javanmardi et al. (2005), Uddin (1999), Espander and Lotfi (2003), Azmi and Paultre (2002), and Ahmadi et al. (2001). In these research works, structural behavior of existing dams in different places were investigated through nonlinear analysis and the results were documented.

In the present research, seismic analysis of arch dams was carried out through finite element analysis on the created structural models. Structural models for existing dams which provide expression of earthquake behavior of dams were created using finite element modeling and the parameters were determined to represent random characteristics. It can be said that accuracy of structural modeling is very critical for accuracy in the analyses.

Probabilistic approach is also associated with testability of model information. Probabilistic seismic evaluation methods cover the approaches which are based on the expression as probability of the behavior of existing structures and that are widely used today. The risk in the

analysis of structural systems is the probability of occurrence of an event which is undesirable. Generally, the structural reliability is based on the possibility of collapse of the structure and is also referred to as breaking performance of the structures in the analysis (Korkmaz, 2005). The application of deterministic approaches, excluding probabilistic seismic analysis may be insufficient in the expression of the seismic structural behavior. The uncertainty and lack depend on the different reasons in the numerical expressions such as capacity and response in the analysis. Due to such uncertainties which cannot be expressed probabilistically, it is not possible to conclude that the results of deterministic methods are valid for every case. Limited information affects the results, hence, sensitivity analysis can be carried out as a part of probabilistic approach. In Figure 1, risk analysis steps used in seismic risk analysis were given as detailed. The probabilistic seismic analysis is expressed as the inclusion to the structural analysis of the concept of the limit state exceedance probability accepted for fracture cases. Fragility analysis is the expression of the vulnerability of the structure (Castaldo et al., 2015, 2016 a, b, 2017 a, b).

Fragility analysis used in analyzing the building structures is also used in the determination of damage of the dam structures. As a result of the analysis performed with the chosen design parameters, the parameters effecting the structural behavior are obtained. The behavior parameters obtained in the results analysis would become a function of the design parameters. On the other hand, in the determination of non-specific

(a)

(b)
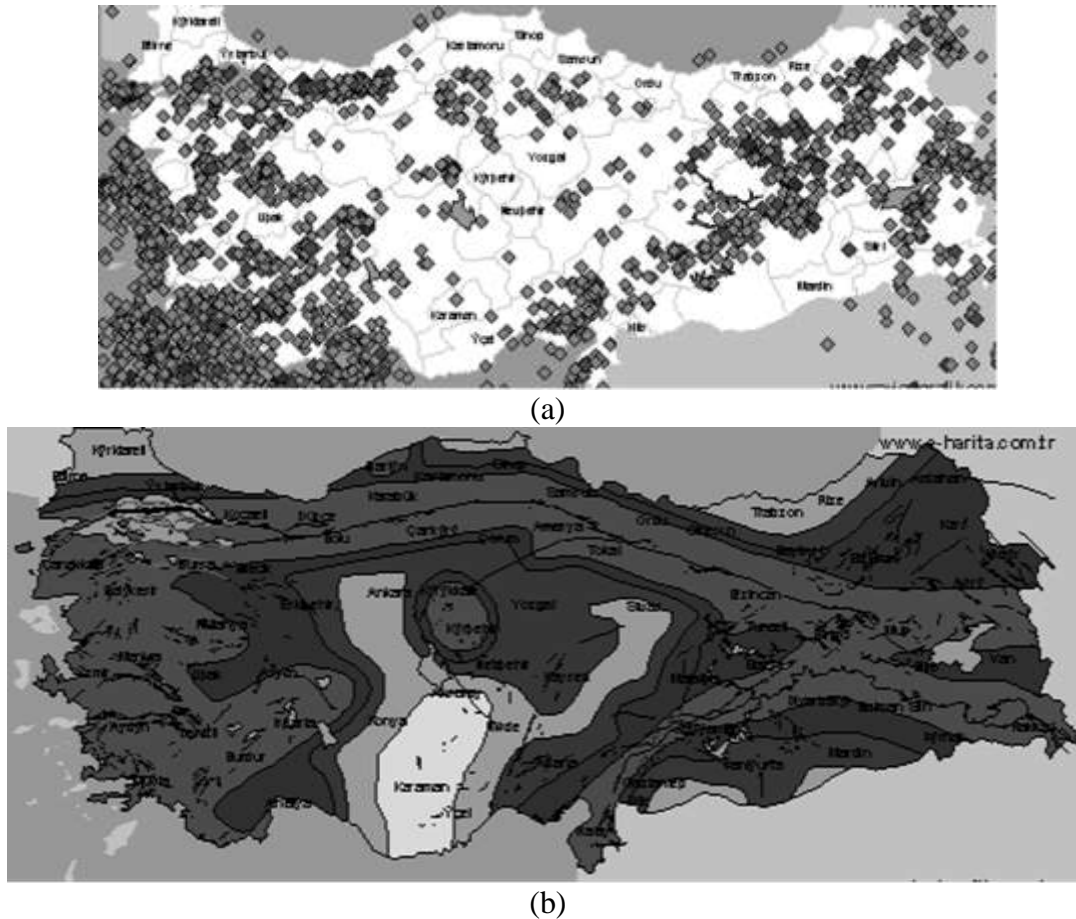
Figure 2. Turkish Earthquake and Seismic Map. (a) Turkish map with epicentres (M>4) of the earthquakes between 1973-2009 with USGS data (Turkish Earthquake Site, 2009) (b) Turkish seismic map with fault lines (Turkish Earthquake Site, 2009).

behavioral parameters, it may be necessary to implement the probabilistic seismic damage models and probabilistic analysis methods. Therefore, considered criteria should be evaluated in each step to determine the effectiveness on the analysis. This step is called the evaluation step.

The concept of probability goes back to 1940s which was used first time in the determination of seismic safety (Marek, 2003). In recent years, probabilistic seismic analysis methods have shown significant improvements. User loads, external influences and the uncertainties in material properties has required the use of the probabilistic approach in the seismic analysis.

Using probabilistic analysis was based on the concepts of uncertainty and randomness. To complete these analyses correctly, the data used in the analysis are important for the accuracy of the analysis. Defining concept of probability is neccessary to provide risk assesment analysis. Therefore, in the analyses, risk and exceedance probabilities are obtained. When performing analysis, the concepts of seismic damage curves, limit states of the structures and risk levels are given. The

probability analysis is of great importance in terms of the determination of the acceptable risk level.

SEISMIC SETTING

Earthquakes hit Turkey very often, causing serious damage to exisiting buildings and led to a significant life and economic loss. In 1999, two major earthquakes hit the northwestern region of Turkey and damaged or destroyed many buildings. The seismic activity of the country might be best explained by illustrating the epicenters and magnitudes of the earthquakes (M>4) that have occurred in Turkey through history as in Figure 2a. In Figure 2a, it is clearly seen that, northwestern and western Turkey are areas of significant seismic activity. In Figure 2b, Turkish seismic map with fault lines is shown (Turkish Earthquake Site, 2009). Table 1 shows the recent major earthquakes in Turkey (Inel et al., 2008).

Turkey is located in the southeast side of Europe and covers an area of 77.95 million ha. Almost one-third of

Table 1. Recent major earthquakes in Turkey.

Date (dd/mm/yy)	Magnitude	Location	Latitude (N)	Long. (E)	Depth (km)	Deaths	Injured	Heavily damaged buildings
13.03.1992	6.8	Erzincan	39.68	39.56	27	653	3850	6702
01.10.1995	5.9	Dinar	38.18	30.02	24	94	240	4909
27.06.1998	5.9	Adana	36.85	35.55	23	146	940	4000
17.08.1999	7.4	Kocaeli	40.70	29.91	20	15 000	32 000	50 000
12.11.1999	7.2	Duzce	40.79	31.21	11	845	4948	15 389
03.02.2002	6.5	Afyon	38.46	31.30	6	42	325	4401
01.05.2003	6.4	Bingol	38.94	40.51	6	176	521	1351

this area (28 million ha) can be classified as cultivable land. About 8.5 million ha is feasibly irrigable with the use of available and appropriate technology. However, only 2.5 million ha land has been irrigated up until now (Tosun et al., 2007). Water and energy supplies are key factors that affect the economic development and environmental improvement of Turkey. The total number of dams that are constructed in Turkey is 1,200 (Tosun et al., 2007). In Turkey, high magnitude earthquakes that potentially cause hazards on dams occur frequently. High magnitude earthquakes can cause: deep cracks along or perpendicular to the crest, deterioration of the rip-rap or sealing system and displacement or settlement of the crest. Therefore, it is necessary to determine the displacements and stresses that occur during the construction of dams. Displacements and stresses vary depending on the material properties and earthquake's features.

SEISMIC ANALYSIS AND DESIGN ASPECTS OF EXISTING DAMS

Assessment of the impact of earthquake on existing dams can be challenging, as it requires more sophisticated analysis tools than those used for the usual analyses. Understanding the behavior of a dam is also a challenging task as the behavior is shaped by the complex interaction between various components of the dam (Yalin, 2013). Over the decades, significant developments have been accomplished in understanding the dynamic response of dams (Espander and Lotfi, 2003; Azmi and Paultre, 2002). Significant progress has been attained in the linear-elastic dynamic analysis of the existing dams and the equivalent linear method has been developed for earthfill/rockfill dams, which has been widely used for practical applications. Accuracy of nonlinear dynamic analysis of the existing dams is related with defining joint behavior and cracking in the anlaysis. These definitions directly affects the structural modeling and analysis. For instance, time history analyses are one of the important analyses tools to understand the structural behavior. Through the existing research works, significant progress has been achieved in understanding

the dynamic characteristics of dams (Espander and Lotfi, 2003; Azmi and Paultre, 2002; Ahmadi et al., 2001).

The International Commission on Large Dams (ICOLD) and FEMA committees has prepared number of guidelines on various aspects of seismic analysis, design and seismic monitoring of the existing dams. These guidelines are considered as seismic codes in the countries which do not have any specific codes or regulations for dams (ICOLD, 1989; FEMA, 2005).

In this study, the earthquake safety of existing arch dams in Turkey were examined. Investigated arch dams are Gökçekaya, Oymapinar, Karakaya, Gezende, Sir, Berke, Deriner, Ermenek Dams. The arch dams and their properties was presented in Table 2 (Dumanoğlu and Akköse, 2003). The material properties of the arch dams in Turkey are presented in Table 3. Gökçekaya Dam is located in Eskişehir, Oymapinar Dam is located in Antalya, Karakaya Dam is located in Diyarbakir, Gezende Dam is located in Mersin, Sir Dam is located in Kahramanmaraş, Berke Dam is located in Osmaniye, Deriner Dam is located in Artvin, and Ermenek Dam is located in Karaman in Turkey.

Dynamic analysis was carried out for selected arch dams. The dynamic equilibrium equations were integrated by using the step by step numerical processing. Direct integration is to make step by step processing without transforming to a different form of the equations (Bathe, 1996). The dynamic analysis were made by applying 60 earthquake acceleration records of A, B and C soil classes. The properties of earthquakes are presented in Tables 4 to 6. Seismic probability analysis were made by using the values obtained. The mass adding approach of Westergard was used at hydrodynamic pressure estimation (Westergard, 1933). According to the Westergard approach, the liquid impact was calculated by the following equations.

$$P = C.g.m \tag{1}$$

$$m = (7/8)\sqrt{H.y(w/g)} \tag{2}$$

$$P = (7/8)cw\sqrt{Hy} \tag{3}$$

Table 2. The arch dams in Turkey and their properties.

Arch Dams	Heights		Crest Elevation (m)	Body Volume	Crest Length (m)	Crest Width (m)
	From Basic	From Thalveg				
Gökçekaya	158	113.5	392	650	479.66	6
Oymapinar	185	157	185	676	360	5
Karakaya	173	158	698	2000	462	12
Gezende	75	71	335	83	120	7.5
Sir	116	106	443	494	360	5
Berke	201	186	346	7292	270	4.6
Deriner	253	209	397	2037	720	18
Ermenek	218	210	700	272	123	7

Table 3. The material properties of dams.

Dams	Concrete class
Gökçekaya	C25
Karakaya	C30
Gezende	C30
Sir	C25
Berke	C30
Ermenek	C35
Deriner	C30
Oymapinar	C30

Table 4. The earthquake data of A soil class.

Number	Earthquake	Date	Magnitude (Mw)	Records	Ground Velocity (cm/s)	Ground Acc. (g)	Focus Length (km)
1	Anza (Horse Cany)	25/02/1980	4.9	AZF315	2.6	0.066	12.1
2	Morgan Hill	24/04/1984	6.2	G01320	2.9	0.098	16.2
3	Coyote Lake	06/08/1979	5.7	G01320	8.3	0.132	9.3
4	Landers	28/06/1992	7.3	GRN180	14.1	0.041	141.6
5	Landers	28/06/1992	7.3	ABY090	20	0.146	69.2
6	Landers	28/06/1992	7.3	SIL000	3.8	0.05	51.7
7	Landers	28/06/1992	7.3	29P000	3.7	0.08	42.2
8	Loma Prieta	18/10/1989	6.9	G01090	33.9	0.473	11.2
9	Loma Prieta	18/10/1989	6.9	SGI360	8.4	0.06	30.6
10	Loma Prieta	18/10/1989	6.9	MCH000	3.5	0.073	44.8
11	Loma Prieta	18/10/1989	6.9	PTB297	12.9	0.072	78.3
12	Lytle Creek	12/09/1970	5.9	CSM095	1.8	0.071	88.6
13	N. Palm Springs	08/07/1986	6.0	AZF225	5.8	0.099	20.6
14	N. Palm Springs	08/07/1986	6.0	ARM360	3.4	0.129	46.7
15	N. Palm Springs	08/07/1986	6.0	H02090	1.8	0.093	45.6
16	N. Palm Springs	08/07/1986	6.0	H02000	1.9	0.07	57.6
17	Whittier Narrows	01/10/1987	5.3	MTW000	40	0.123	20.4
18	Anza (Horse Cany)	25/02/1980	4.9	AZF225	3.3	0.065	12.1
19	Anza (Horse Cany)	25/02/1980	4.9	PTF135	5.1	0.131	13
20	Anza (Horse Cany)	25/02/1980	4.9	TVY135	1.7	0.081	5.8

Table 5. The earthquake data of B soil class.

Number	Earthquake	Date	Magnitude (Mw)	Records	Ground Velocity (cm/s)	Ground Acc. (g)	Focus Length (km)
1	Parkfield	28/06/1966	5.6	C12320	6.8	0.0633	14.7
2	Morgan Hill	24/04/1984	6.2	GIL067	3.6	0.1144	16.2
3	Kocaeli	17/08/1999	7.4	ARC000	17.7	0.2188	17
4	Morgan Hill	24/04/1984	6.2	G06090	36.7	0.2920	11.8
5	Coyote Lake	06/08/1979	5.8	G06230	49.2	0.4339	3.1
6	Northridge	17/01/1994	6.7	ORR090	52.1	0.5683	22.6
7	Loma Prieta	18/10/1989	7.1	CLS000	55.2	0.6437	5.1
8	Kobe	16/01/1995	6.9	KJM000	79.3	0.8213	6.9
9	Santa Barbara	13/08/1978	7.2	SBA222	16.3	0.203	14.0
10	Livemor	27/01/1980	7.4	LMO355	9.8	0.252	8.0
11	N. Palm Springs	08/07/1986	6.0	DSP000	33.8	0.331	8.2
12	N. Palm Springs	08/07/1986	6.0	FVR045	41.2	0.129	13.0
13	Northridge	17/01/1994	6.7	TPF000	17.6	0.364	37.9
14	San Fernando	02/09/1971	6.6	ORR021	15.6	0.324	24.9
15	Whitter Narrows	10/01/1987	6.0	ALH180	22	0.333	13.2
16	Kocaeli	17/08/1999	7.4	SKR090	79.5	0.376	3.1
17	Victoria, Mexica	09/06/1980	6.1	CPE045	31.6	0.62	34.8
18	Anza (Horse Cany)	25/02/1980	4.9	BAR225	2.6	0.047	40.6
19	Anza (Horse Cany)	25/02/1980	4.9	RDA045	6.7	0.097	19.6
20	**Borrego Mtn**	09/04/1968	6.8	PAS270	4.7	0.090	203.0

Table 6. The earthquake data of C soil class.

Number	Earthquake	Date	Magnitude (Mw)	Records	Ground Velocity (cm/s)	Ground Acc. (g)	Focus Length (km)
1	Borrego Mtn	09/04/1968	6.8	A-ELC180	26.3	0.13	46.0
2	Borrego Mtn	09/04/1968	6.8	A-PEL090	2.9	0.012	217.4
3	Borrego Mtn	09/04/1968	6.8	A-TLI249	2.8	0.01	195.0
4	Coyote Lake	06/08/1979	5.7	G02140	40.0	0.339	7.5
5	Coyote Lake	06/08/1979	5.7	G03050	40.0	0.272	6.0
6	Coyote Lake	06/08/1979	5.7	G04270	25.0	0.248	4.5
7	Coyote Lake	06/08/1979	5.7	HVR150	15.0	0.039	31.2
8	Imperial Valley	15/10/1979	7.0	I-ELC180	29.8	0.313	8.3
9	Imperial Valley	15/10/1979	7.0	H-AEP045	42.8	0.327	8.5
10	Imperial Valley	15/10/1979	7.0	H-BCR230	40.0	0.775	2.5
11	Imperial Valley	15/10/1979	6.5	H-BRA315	40.0	0.220	8.5
12	Imperial Valley	15/10/1979	6.5	H-CX0225	40.0	0.275	10.6
13	Hollister	28/11/1974	5.2	A-HCH271	10.3	0.177	10.0
14	Cape Mendocino	25/04/1992	7.1	PET090	89.7	0.662	9.5
15	Coalinga	02/05/1983	6.4	H-C05270	10.8	0.147	47.3
16	Coalinga	02/05/1983	6.4	H-C08000	8.6	0.098	50.7
17	Kern County	21/07/1952	7.4	HOL180	5.3	0.057	120.5
18	Kern County	21/07/1952	7.4	PEL180	6.2	0.058	120.5
19	Loma Prieta	18/10/1989	6.9	HCH090	38.5	0.247	28.2
20	Loma Prieta	18/10/1989	6.9	G02000	32.9	0.367	12.7

P: hydrodynamic pressure, m: mass of liquid, C: the rate   of earthquake acceleration to gravity acceleration, W: the

(a) Three-dimensional view

(b) Upstream view

(c) Downstream view

(a) Top view
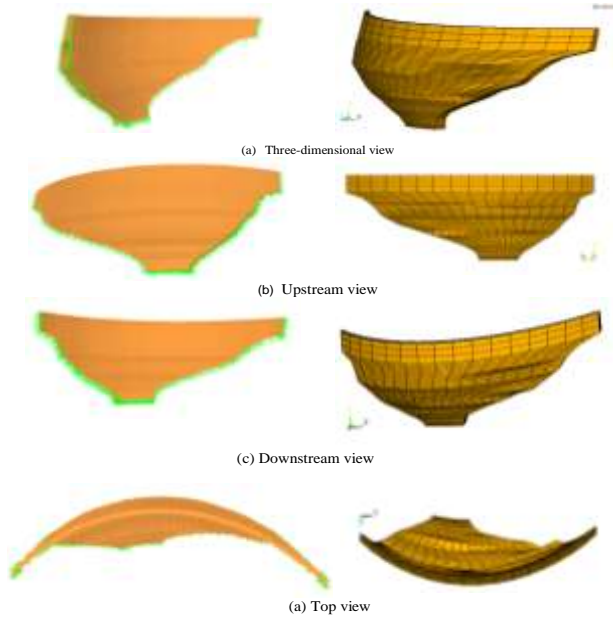
Figure 3. The views modelled of Gökçekaya Dam with SAP2000 (Left) and ANSYS (right).

(a) Three-dimensional view

(b) Upstream view

(c) Downstream view

(d) Top view
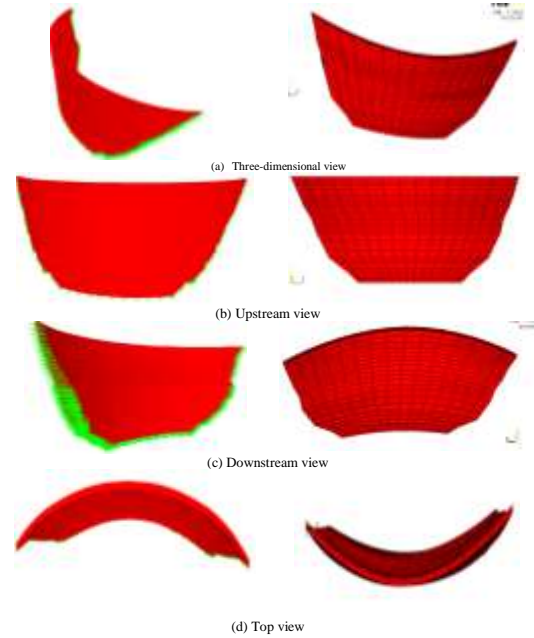
Figure 5. The views modelled of Karakaya Dam with SAP2000 (Left) and ANSYS (right).

(a) Three-dimensional view

(b) Upstream view

(c) Downstream view

(d) Top view
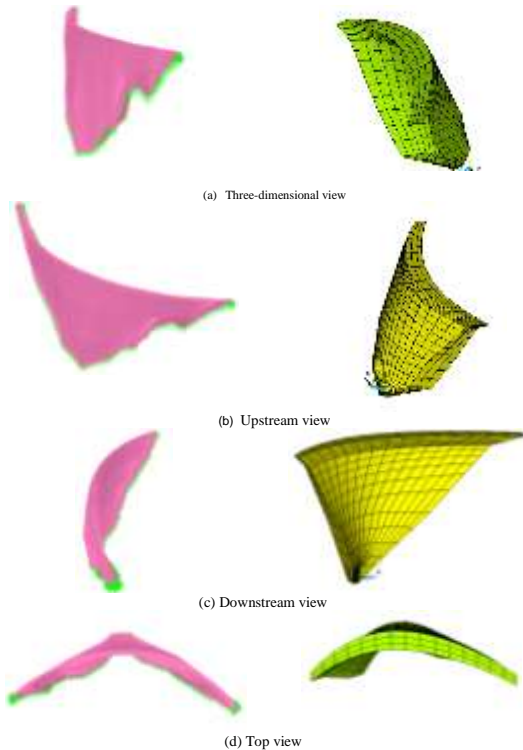
Figure 4. The views modelled of Oymapinar Dam with SAP2000 (Left) and ANSYS (right).

(a) Three-dimensional view

(b) Upstream view

(c) Downstream view

(d) Top view
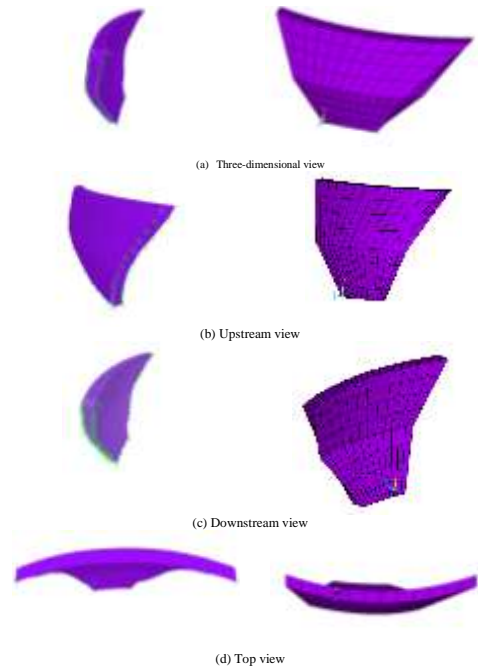
Figure 6. The views modelled of Gezende Dam with SAP2000 (Left) and ANSYS (right).

density of liquid, H: the depth of water, Y: the distance of the water depth to crest level.

Dams were modelled via SAP 2000 V14. The modelled dams are presented between Figure 3 and 10. 60 earthquake acceleration records of A, B and C soil classes have

(a) Three-dimensional view

(b) Upstream view

(c) Downstream view

(d) Top view
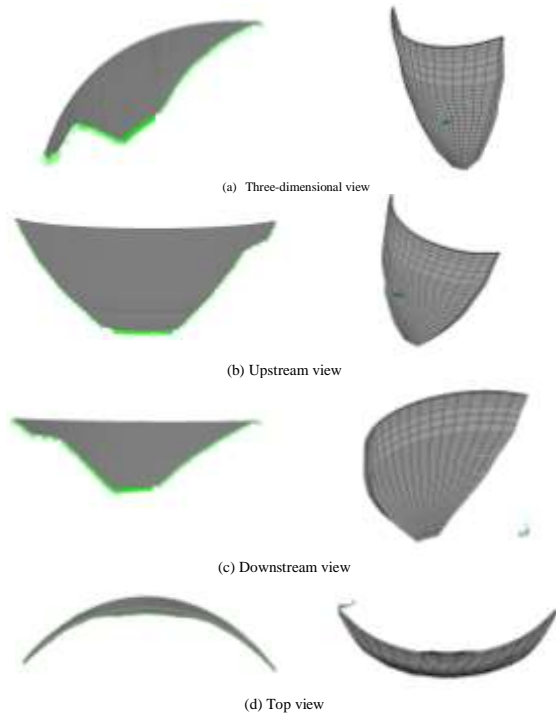
Figure 7. The views modelled of Sir Dam with SAP2000 (Left) and ANSYS (right).

(a) Three-dimensional view

(b) Upstream view

(c) Downstream view

(d) Top view
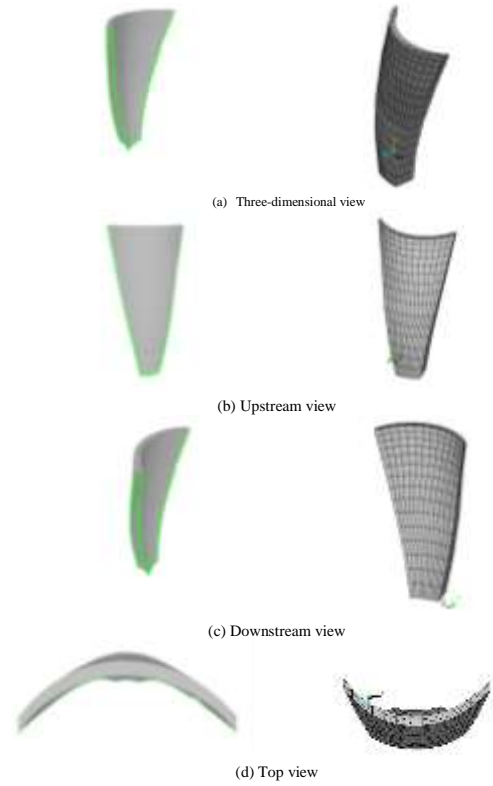
Figure 9. The views modelled of Ermenek Dam with SAP2000 (Left) and ANSYS (right).

(a) Three-dimensional view

(b) Upstream view

(c) Downstream view

(d) Top view
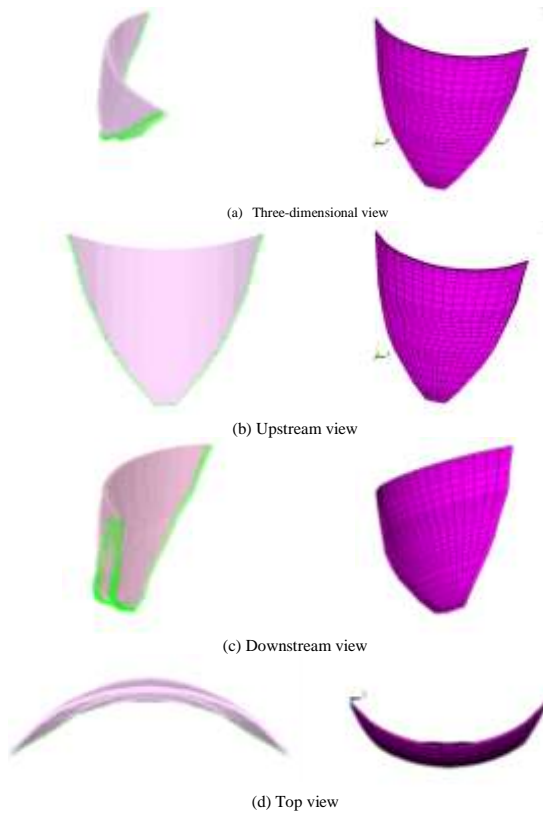
Figure 8. The views modelled of Berke Dam with SAP2000 (Left) and ANSYS (right).

(a) Three-dimensional view

(b) Upstream view

(c) Downstream view

(d) Top view
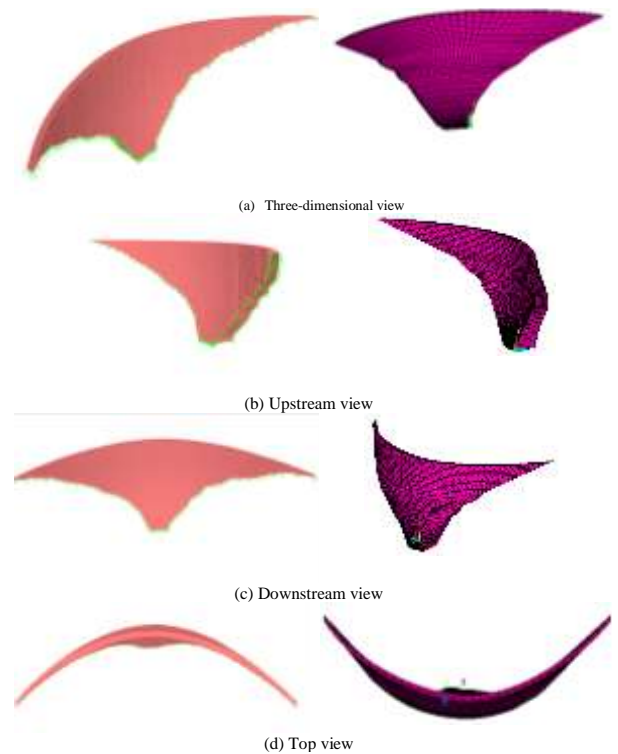
Figure 10. The views modelled of Deriner Dam with SAP2000 (Left) and ANSYS (right).

Table 7. The application steps of the fragility analysis.

| S/N	Approach
1	Acceleration records to be used for the dynamic analysis were chosen and they were classified according to the soil classes.
2	The dynamic analyzes were performed in the time domain.
3	Limit displacement values were determined for each dam and every one earthquake data.
4	Behavior of the system and displacement values were determined.
5	When the displacement demands compared with the limit values of prescribed damage levels, the cases of dams were determined.
6	The lognormal distribution parameters of fragility curves plotted according to the displacement were obtained as standard deviation and mean
7	Exceedence probability was controlled and each level was checked.
8	The fragility curves obtained were classified according to the soil class, X and Y direction and the situation whether the effect of the water take consideration
9	Dams were compared with together by giving on a single graph.

(a) A class X direction displacements

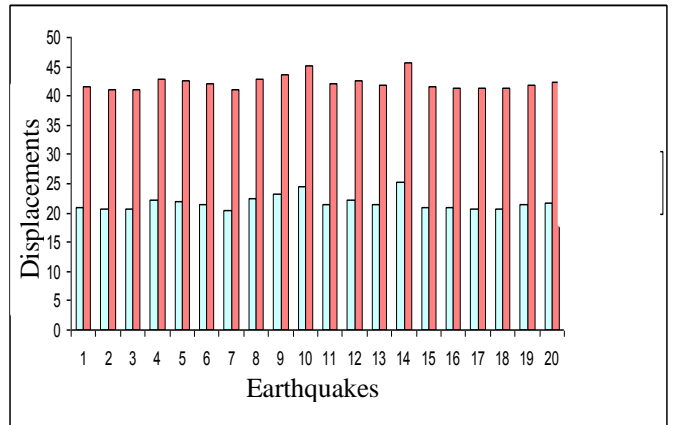(b) A class Y direction displacements

(c) B class X direction displacements

(d) B class Y direction displacements

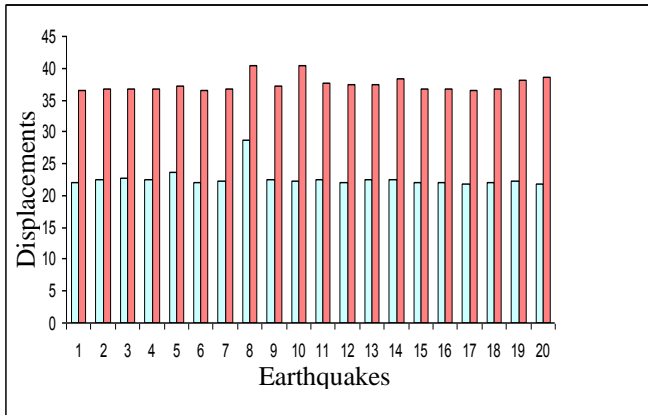(e) C class X direction displacements

(f) C class Y direction displacements
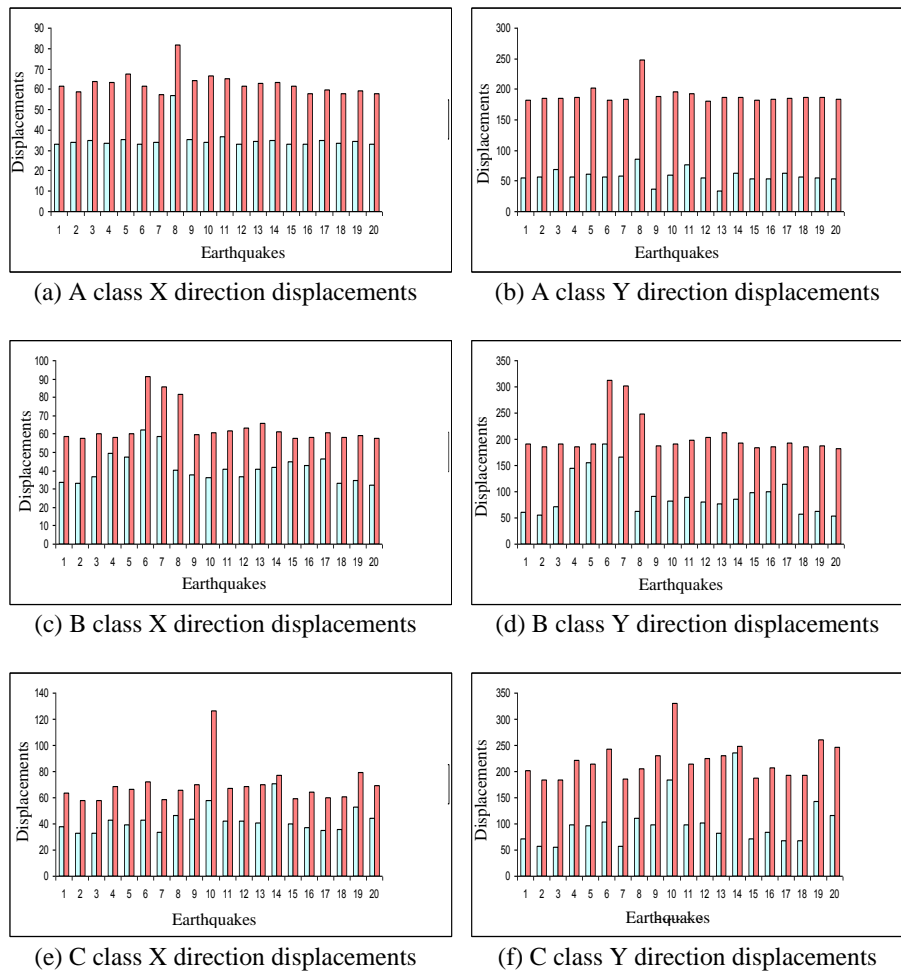
Figure 11. The maximum displacement values of Gökçekaya Dam.

been considered. In the scope of the study, the steps for each dam model were taken into consideration as vulnerability expression as given in Table 7.

Performance assessment of existing dam structures using ground motion data from A, B and C soil classes for Gökçekaya Dam, Oymapinar Dam, Karakaya Dam, Gezende Dam, Sir Dam, Berke Dam, Deriner Dam, and Ermenek Dam, along with displacement values in X and Y directions are presented in Figures 11 to 18 respectively. As seen in Figure 11, the maximum displacement value in X direction in A soil class, Gökçekaya Dam was obtained in Loma Prieta earthquake
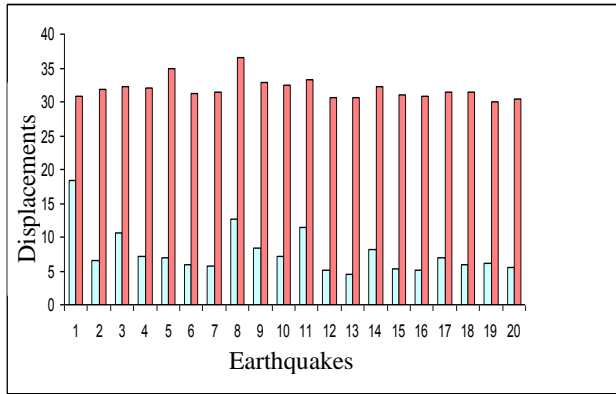
(a) A class X direction displacements
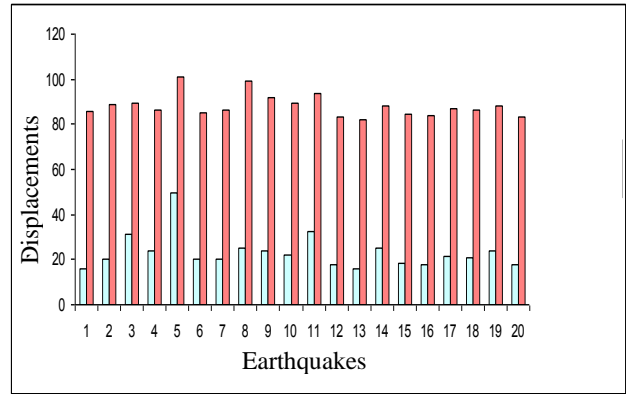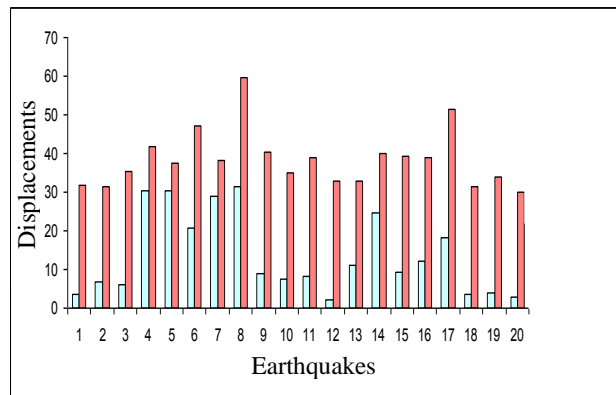
(b) A class Y direction displacements

(c) B class X direction displacements
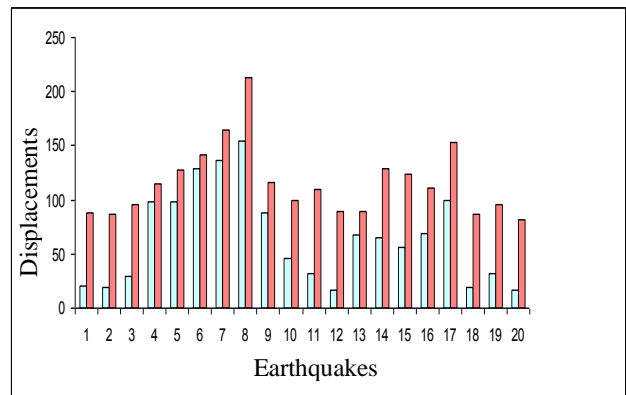
(d) B class Y direction displacements
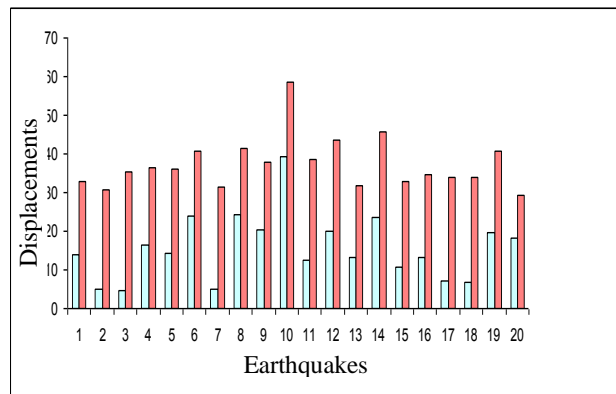
(e) C class X direction displacements
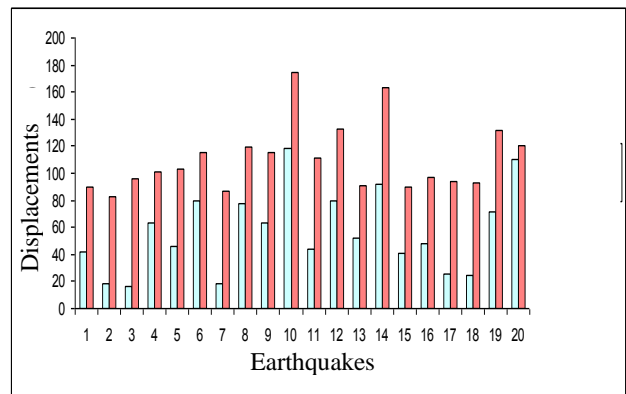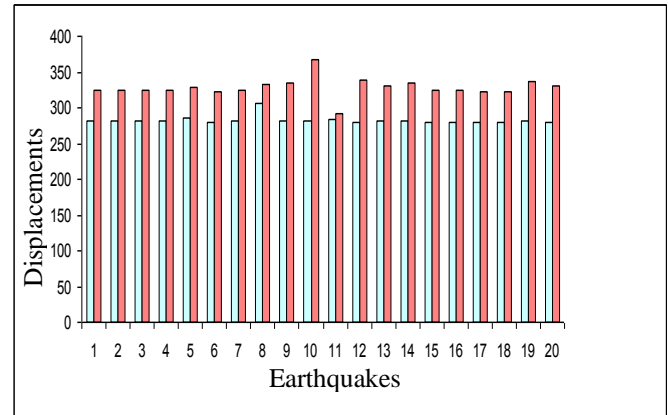

(f) C class Y direction displacements

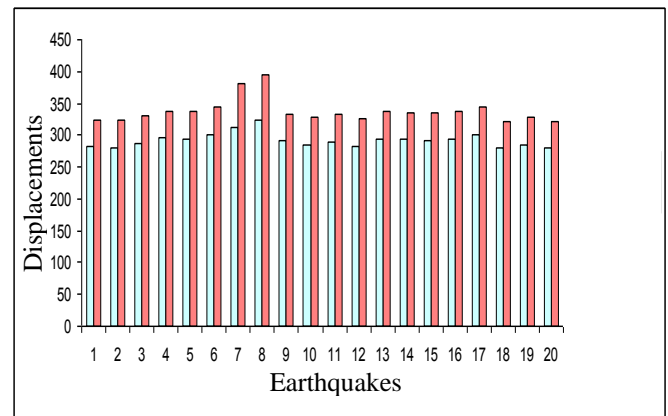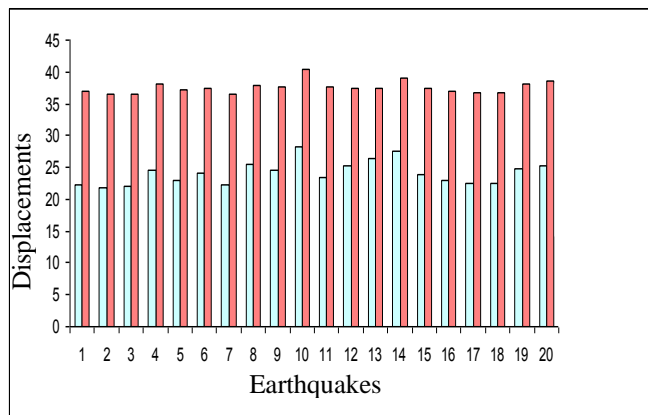**Figure 12.** The maximum displacement values of Oymapinar Dam.

data with number 8. The displacements values occurred as a result of the analyses performed by Loma Prieta earthquake record, viz; maximum 81.6 mm with full case and 56.9 mm with empty case. The magnitude of Loma Prieta earthquake is 6.9 and Loma Prieta earthquake has the most effective ground acceleration in A soil class. The

displacements obtained by using Landers earthquake magnitude (8.3) were smaller values than those obtained by using Loma Prieta earthquake. The focal length of Loma Prieta earthquake is 11.2 km and it is the earthquake having the smallest depth in A soil class. In the results, it was obtained by using number 20 and 1
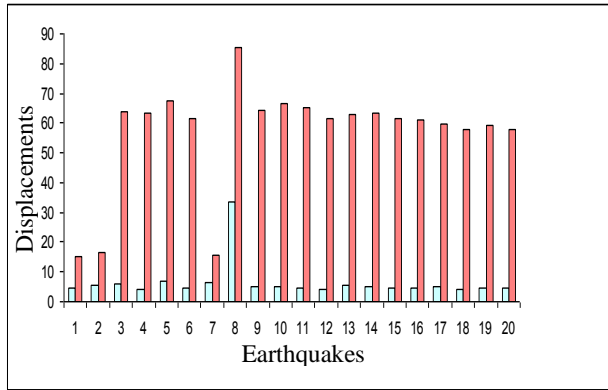
(a) A class X direction displacements
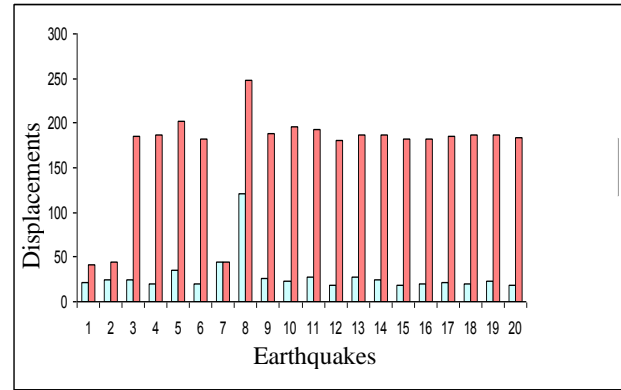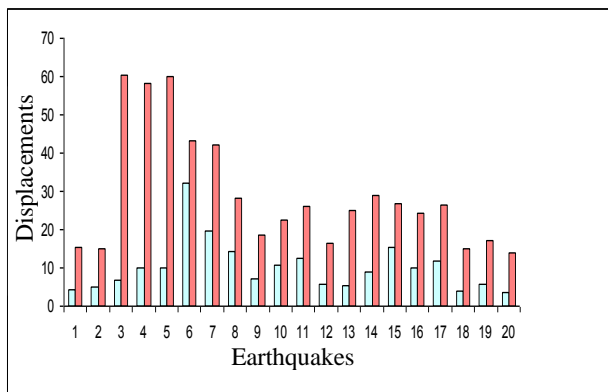
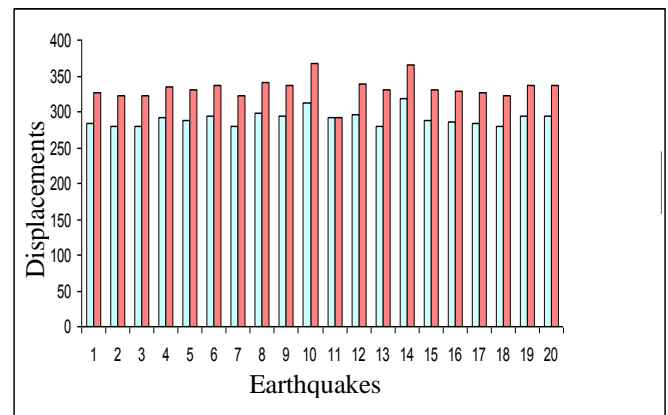(b) A class Y direction displacements

(c) B class X direction displacements
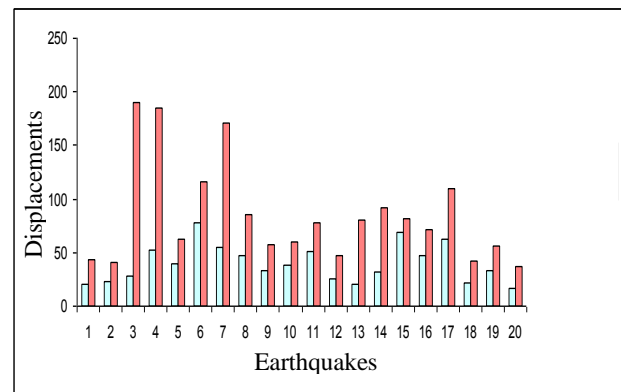
(d) B class X direction displacements
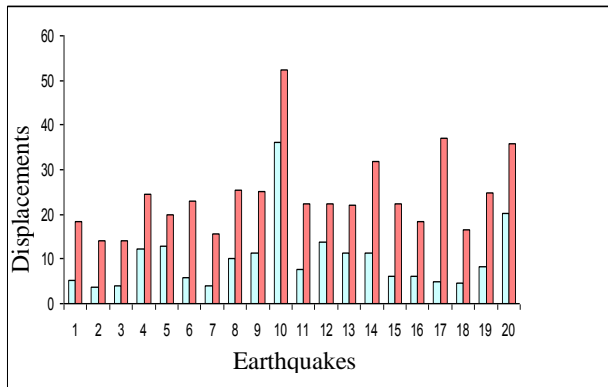
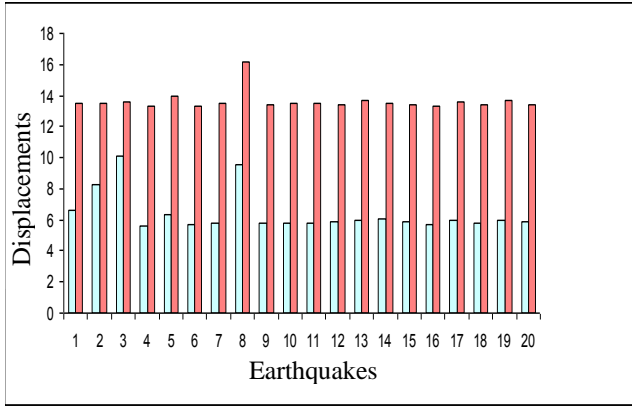(e) C class X direction displacements
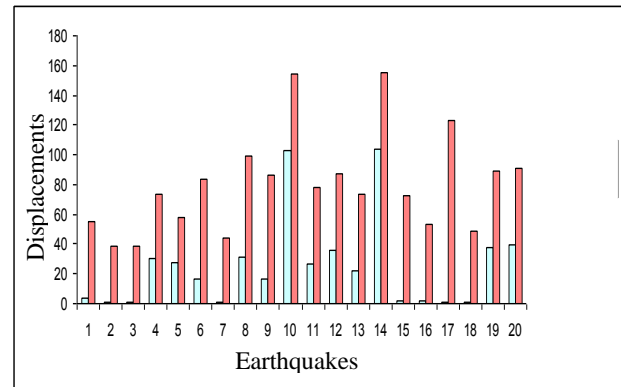
(f) C class Y direction displacements
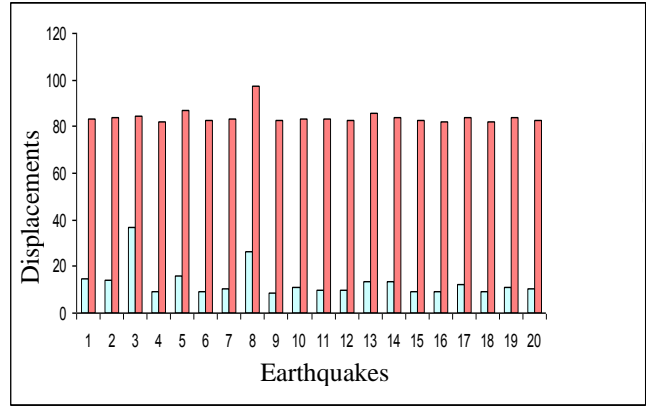
Figure 13. The maximum displacement values of Karakaya Dam.

earthquake gives 32.9 mm and 33 mm displacements, respectively. The magnitude of Anza earthquake number 20 is the smallest value in A soil class. The displacement values close to each other in the empty and full case at X direction were obtained due to the act of water effects on the Y direction. While the biggest displacement value in full case at the Y direction was obtained as 247.6 mm, it

was obtained as 85.4 mm in empty case with Loma Prieta earthquake record number 8. This situation, the of effect ground acceleration value of Loma Prieatra for earthquake number 8, is said to be more than the other earthquakes. The smallest displacement value in empty case was obtained as 33.9 mm with N. Palm Springs earthquake record number 13, and was obtained as
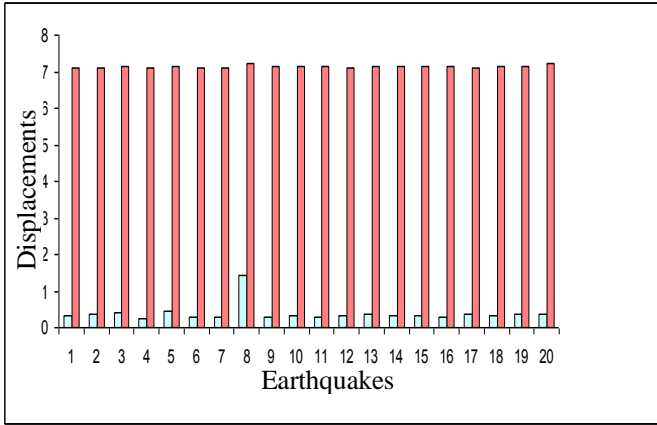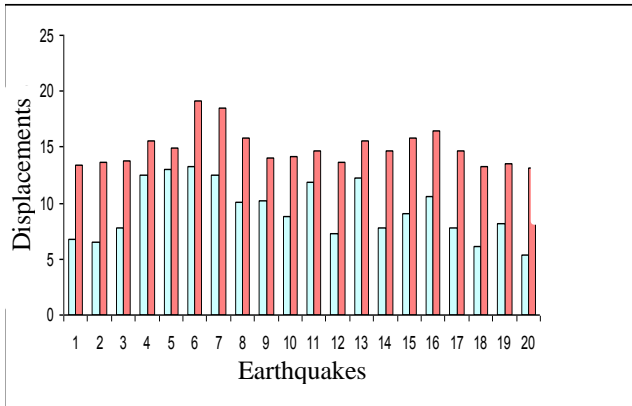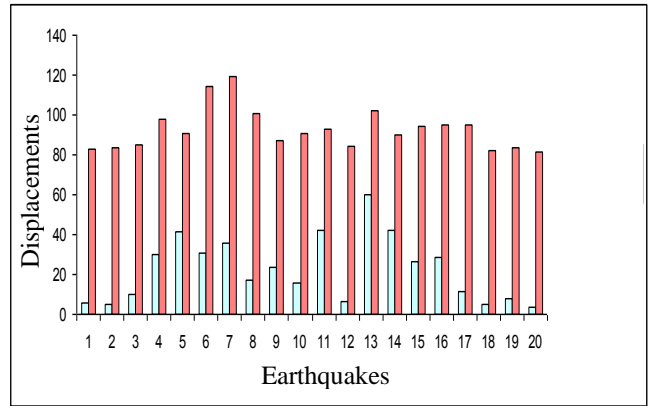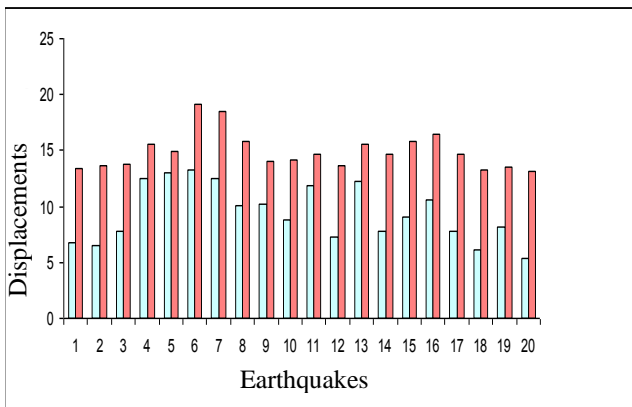
(a) A class X direction displacements
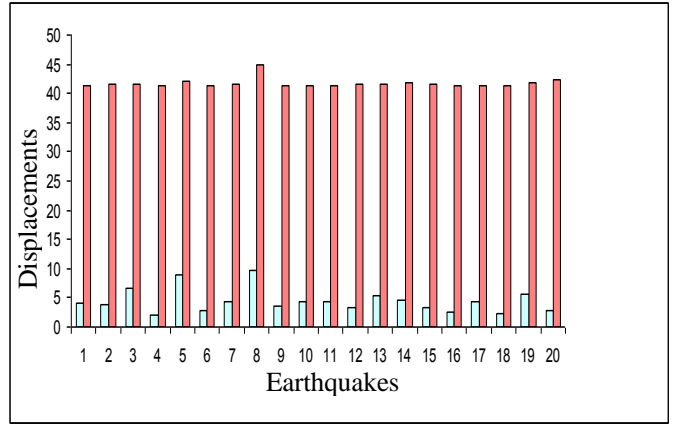
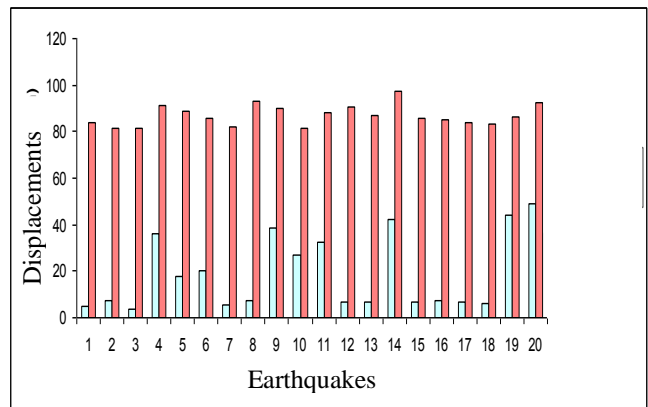(b) A class X direction displacements
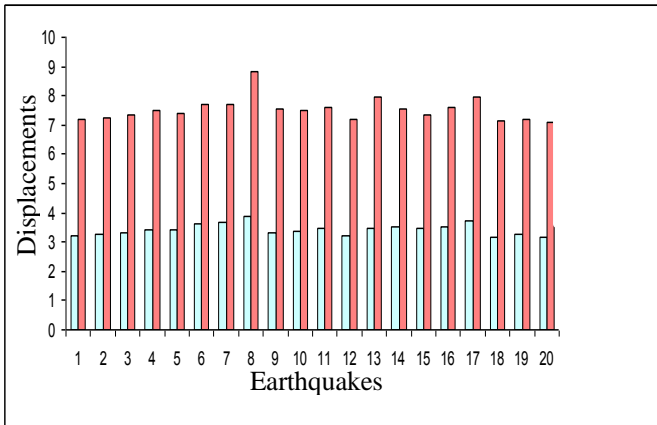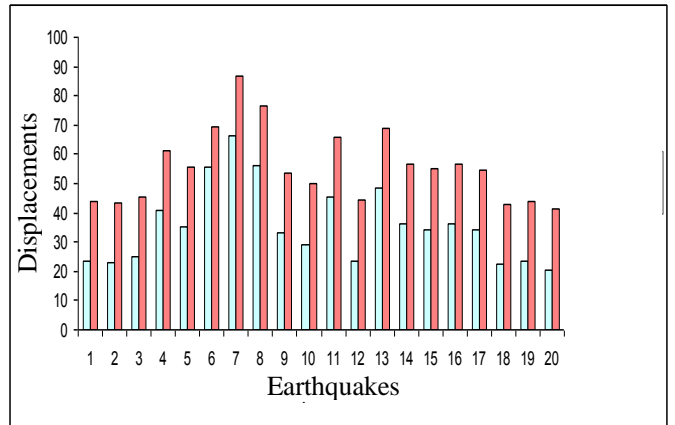
(c) B class X direction displacements

(d) B class Y direction displacements
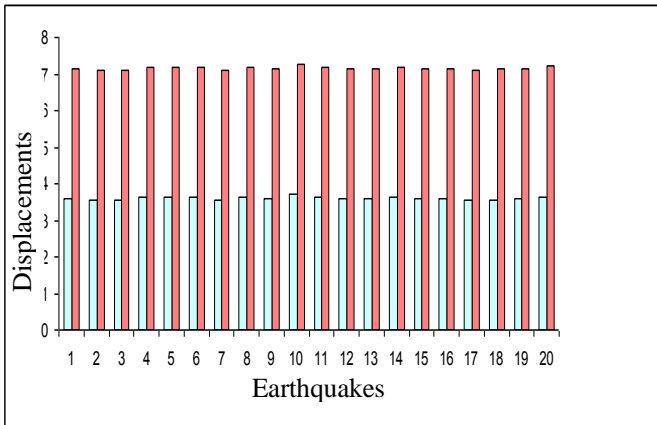
(e) C class X direction displacements

(f) C class Y direction displacements

Figure 14. The maximum displacement values of Gezende Dam.

181.2 mm with Lytle Creek Earthquake number 12 in full case.

For B soil class, the biggest displacement values at X direction were obtained as 62.2 mm with Nortridge data

(a) A class X direction displacements
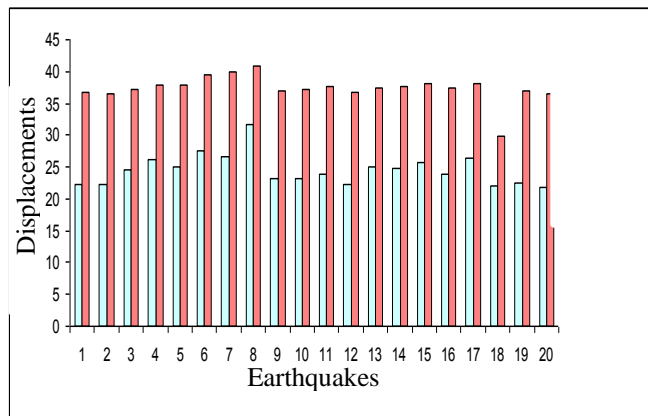
(b) A class Y direction displacements

(c) B class X direction displacements

(d) B class X direction displacements

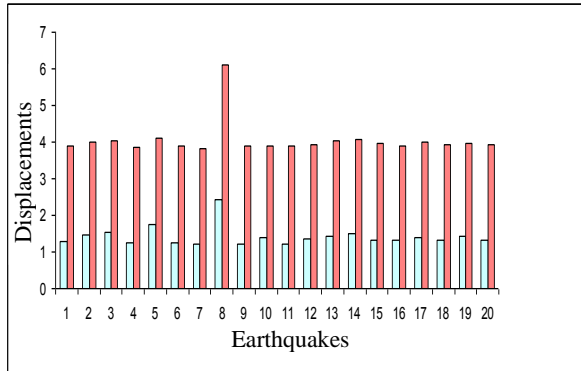(e) C class X direction displacements

(f) C class Y direction displacements

Figure 15. The maximum displacement values of Sir Dam.

in empty case, while 91.4 mm in the full case. The effect of ground acceleration and focus depth of Northridge earthquake number 6 is the biggest value of B soil class. The biggest displacement at Y direction was obtained

with earthquake number 6 with 190.4 mm for empty case and 311.7 mm for full case. The smallest displacement was obtained as 53.5 mm for empty case and 182.9 mm for full case, using earthquake record number 20. These

(a) A class X direction displacements

(b) A class Y direction displacements

(c) B class X direction displacements

(d) B class Y direction displacements

(e) C class X direction displacements

(f) C class Y direction displacements

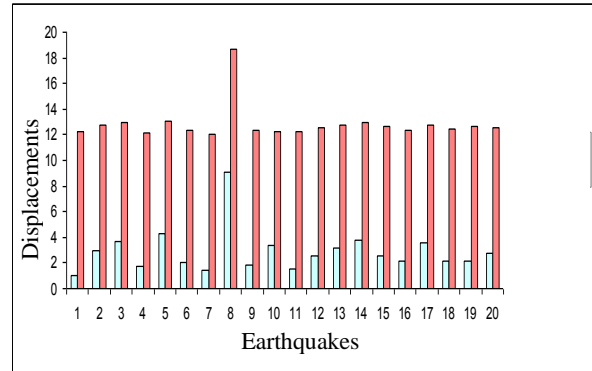**Figure 16.** The maximum displacement values of Berke Dam.

earthquakes were used to obtain the biggest and smallest displacement values at X and Y direction.

In the C soil class, the biggest displacement value at X direction was determined as 126.1 mm for full case with earthquake number 14. The smallest displacement value

was recorded as 32.7 mm for empty case and 57.5 mm for full case by using earthquake data number 14. The smallest displacement value was recorded as 183.2 mm for full case by using earthquake data number 14. The maximum displacement values at X and Y direction were
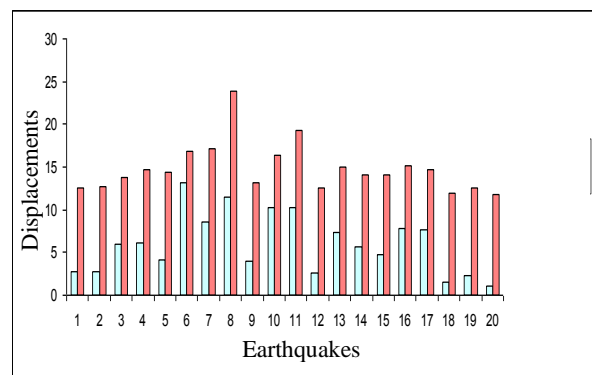
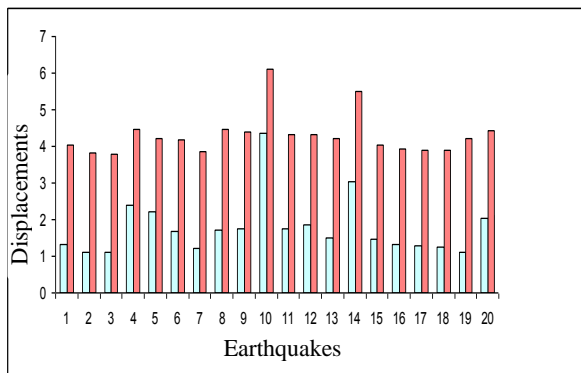(a) A class X direction displacements
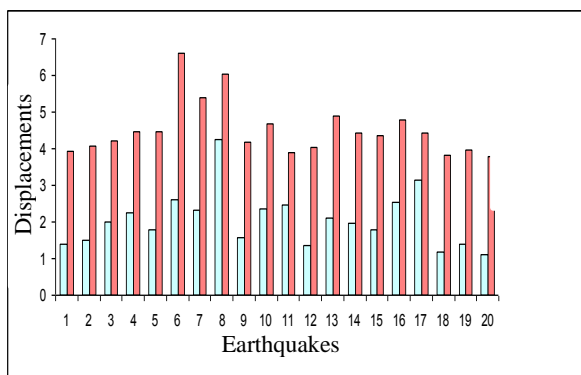
(a) A class Y direction displacements
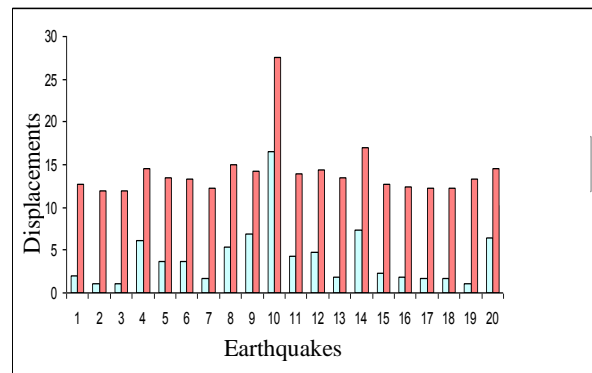

(c) B class X direction displacements

(d) B class X direction displacements

(e) C class X direction displacements

(f) C class X direction displacements

**Figure 17.** The maximum displacement values of Ermenek Dam.

obtained with Cape Mendocino Earthquake with magnitude 7.1.

FRAGILITY ANALYSIS

Fragility analyses were previously used to determine seismic performance of various structures such as nuclear structures (Gergly, 1984) and have been more recently used in the seismic analysis of other structures (Mosalam et al., 1997). This analyses expresses probability to define the damage risk of existing buildings.

Also, fragility is the propability expression of the vulnerability of structures. İt is difficult to predict the structural performance or damage of future eartquakes since their magnitudes and impacts are unknown. To express the seismic risk for a structure and the probability response against the seismic ground motion are quite
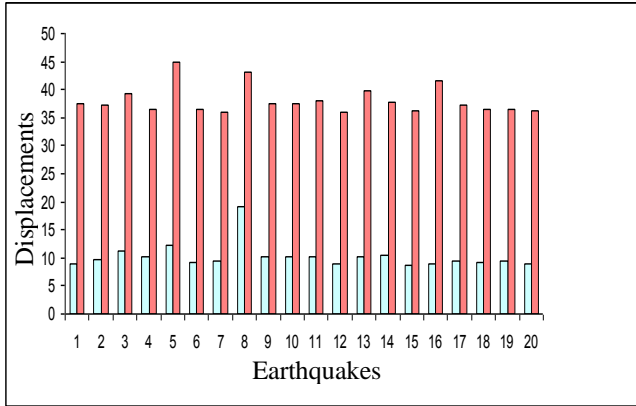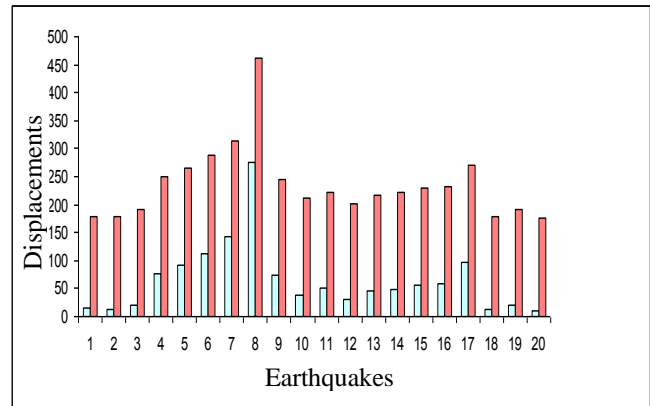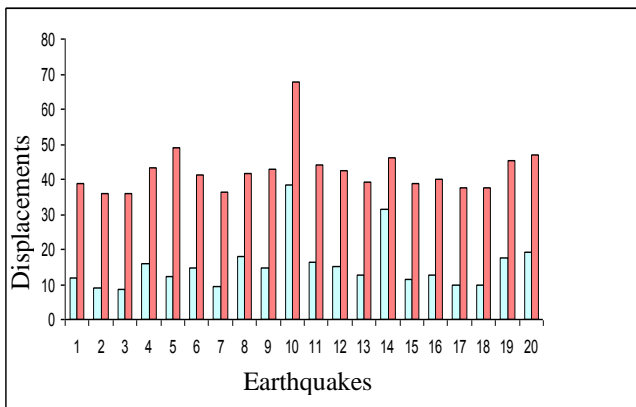
(a) A class X direction displacements
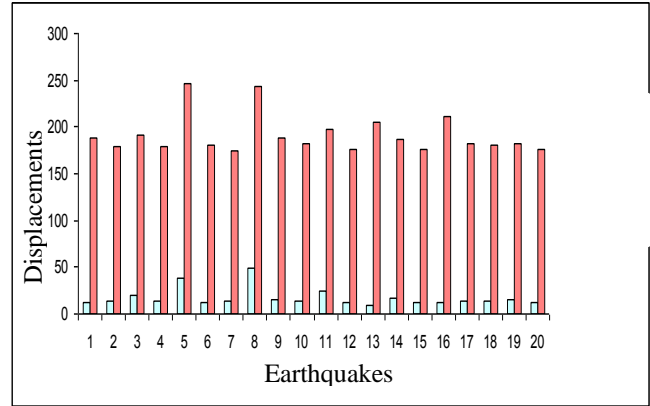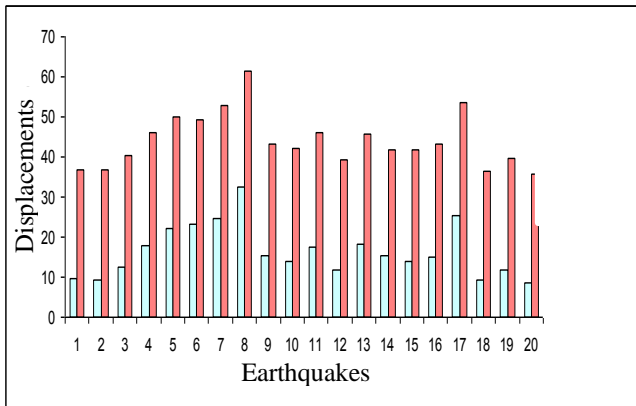
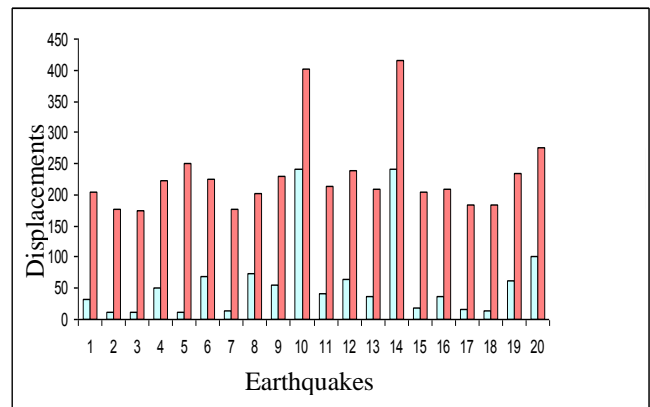(a) A class Y direction displacements

(c) B class X direction displacements

(d) B class Y direction displacements

(e) C class X direction displacements

(f) C class Y direction displacements

Figure 18. The maximum displacement values of Deriner Dam.

important uncertainties in the fragility analysis. Fragility analysis generally can be grouped under three main headings which are uncertainties in modeling of the structure, the uncertainty due to ground motion and

uncertainties in limiting threshold of structure. Fragility curve, which is a function of the earthquake data parameters, is used to assess the probabilistic nature of the structure due to seismic loading. To forecast

structural behavior in future earthquakes, it is necessary to define existing behavior using past earthquake data.

Currently, fragility analysis methods, in FEMA-HAZUS regulations, are given depending on the fragility and the structural response spectra (FEMA, 1999; Dutta and Mander, 1998). In these methods, the probability of exceedance P_f and the distribution of spectral values were adopted in the form of logarithmic normal distribution. Fragility curves can be expressed for an entire structure or single structural component. These curves may be generated using the numerical analysis or experimental results. Fragility analysis is performed in four steps in the form of the identification of grount motion data, definition of ground motion, identification of structural damage and evaluation of the results. The exceedance probability on the y axis, the PGA, PGV or PGD in the x axis is given as one of the spectral acceleration values.

İn the study by Hwang and Jaw (1988), fragility analysis was given in detail while Petrovski and Nocevs (1993) obtained fragility curves of structures which they addresed in their study. İn previous studies, damage probability matrices were developed and they used the value of the rate of the relative story drift as damage parameter in fragility curves (Singhal, 1996; Erberik and Elnasha, 2004); and the value of S_d accepted, confirming a lognormal distribution for fragility curves, was used. Karimi and Bakhshi (2006) proposed fragility curves for masonry structures, using Cumulative Absolute Velocity (CAV) as ground motion parameters. Park-Ang model (1985) was used as damage parameter in their study. Rubinstein (1989) in consideration of the uncertainties in the structural parameters used Monte Carlo simulation technique. Karim and Yamazaki (2003) choose Park-Ang model as damage parameter studies in which they proposed the fragility curve for bridges, using the dynamic analysis beyond linear PGA and PGV values and adopted the Lognormal distrubition as ground motion parameter; while in a later study they considered PGA, PGV and SI as ground motion parameter in their study (Karim and Yamazki, 2003). Their expression was simplified in terms of structural features, using the linear regression as the parameters for lognormal distribution. Shinozuka et al. (2000a) used section ductility demand as damage parameter which was derived of the fragility curves with time history and static analysis approach, using two different analytical approach for the bridges. In another study, the authors adopted PGA values as a part of lognormal distribution, which was used as ground motion parameter. Lognormal distribution parameters were determined by the maximum likelihood method. In the study, results were evaluated as a statistical analysis to sketch empirical and analytical fragility curves for bridges, and the ductility demand was used as damage parameter (Shinozuka et al., 2000b). Kim and Shinozuka (2004) used PGA parameter as lognormal distribution of ground motion parameters. In the study, they evaluated

the effect of reinforcement in the bridge columns. Tsopelas and Pekcan (1999) performed a research on the reinforcement and suggested an improvement, using seismic fragility curves and performance methods. They focused on the modeling with the fragility analysis of the structural behavior. In their method, structural behavior is directly applied on a structure. All these studies can be used as a part of determining the probabilistic structural behavior.

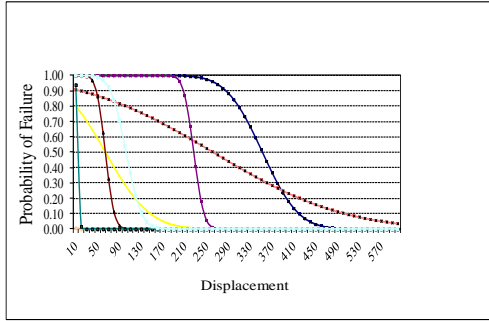## PROBABILISTİC SEISMIC ASSESSMENT OF ARCH DAMS

Various research works evaluated dams and the probabilities were performed using fragility analysis, which relates to evaluating the probabilistic seismic behavior of dams. Among them, Chopra and Gregory (1987) discussed the fragility analysis of dams. In the study performed by Ellingwood and Teike (2001), detailed information about the fragility analysis of dams was given and the fragility analysis of the concrete gravity dams was expressed in the study's scope. Another significant study carried out was by Papadrakakis et al. (2008). They described a new approach to increase the accuracy of probabilistic demand definition in seismic areas.

In the present study, probabilistic seismic analysis of arch dams was performed using fragility analysis. The scope of the study covers fragility analyses carried out and probabilistic seismic behavior of arch dams as a result of the analysis. Fragility was expressed with a conditional probability expression in form of the probability of exceedance:
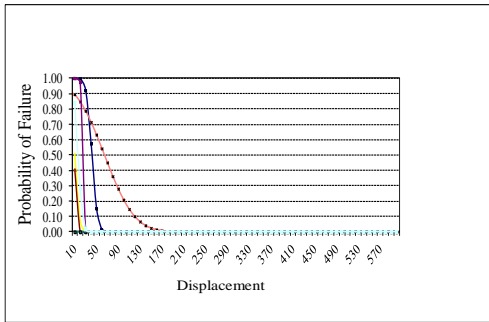
$$\text{Probability of exceedance} = P[R \geq r \,|\, I] \qquad (4)$$

Here, R: the structural response calculated at the result of analysis; r: the damage level predicted for the minimum value of the structural response; I: ground motion parameter used as the random variable for the purpose of calculating the damage limit state of the structural response. The data used for the fragility curves were obtained from past earthquakes, results of experiments, results of analysis or engineering experiences.
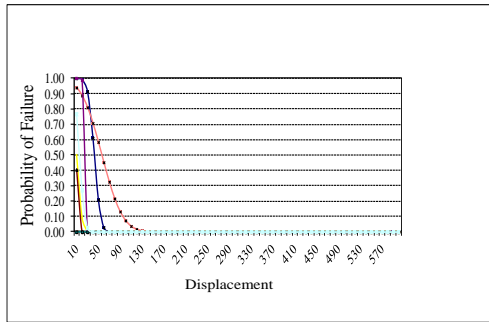
The graphs for A, B and C soil classes in the empty and full cases of dams were obtained. The fragility curves obtained for all soil classes in Figure 19 and Figure 20 were presented for X and Y directions respectively, without considering the water effect. The fragility curves obtained for all soil classes in Figures 21 and 22 were presented for X and Y directions respectively, with consideration for the water effect. It was seen that the yield and collapse limit state as well as exceedance probabilities have increased in this order: Ermenek, Oymapinar, Gezende, Karakaya, Berke, Deriner,

a) For A soil class
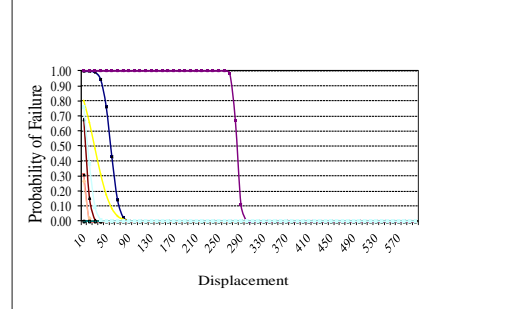

b) For B soil class

c) For C soil class

| ■ Gökçekaya | ✕ Oymapınar | Karakaya | ♦ Gezende |
| ■ Sır | Berke | ■ Ermenek | Deriner |

Figure 19. The X-direction fragility curves obtained without taking into account the water effect for all soil classes.

a) For A soil class

b) For B soil class

c) For A soil class

| ■ Gökçekaya | ✕ Oymapınar | Karakaya | ♦ Gezende |
| ■ Sır | Berke | ■ Ermenek | Deriner |

Figure 20. The Y-direction fragility curves obtained without taking into account the water effect for all soil classes.
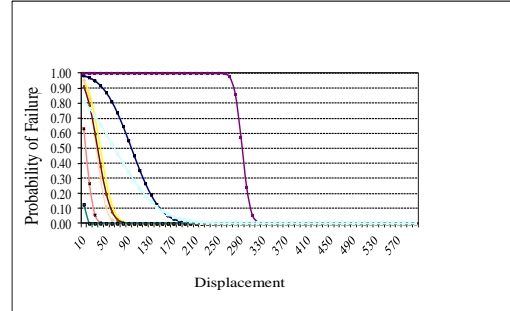
Gökçekaya and Sir Dams for empty and full cases. This order can be seen in the Fragility curves in Figures 19 to 22.
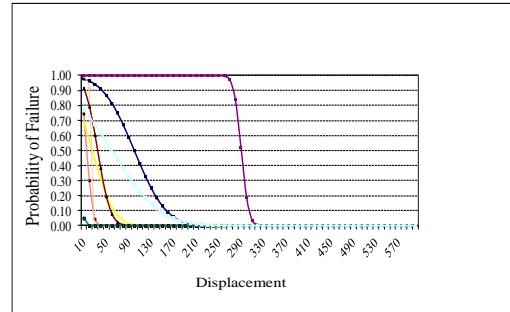
Conclusion

The results of the dynamic analysis were used in the propabilistic seismic evaluation researches performed within this scope of study. Exceedance probability of displacement values were determined using the dynamic analysis, and the fragility curves were plotted. The graphs were created under this section with these values, by obtaining exceedance probabilities against each displacement value in the fragility curves plotted. All dams can be seen on a graph using this approach. In the result of this study performed, sepeate graphs were obtained for A, B and C soil classes. The fragility curves were obtained by considering the effect of water and were also obtained for all soil classes as presented respectively for X and Y directions without taking into account the effect of water. When the graphs were examined, It was seen that the yield and limit state exceedance probabilities increased in this order: Ermenek, Oymapinar, Gezende, Karakaya, Berke, Deriner, Gökçekaya and Sir Dams for empty and full cases.

a)   For A soil class

b)   For B soil class

c)   For C soil class

Figure 21. The X-direction fragility curves obtained taking into account the water effect for all soil classes.
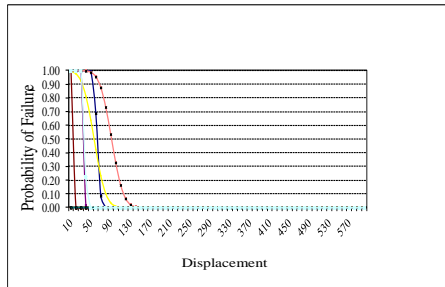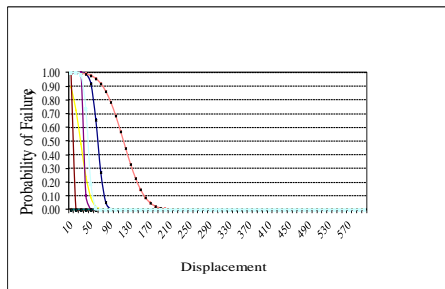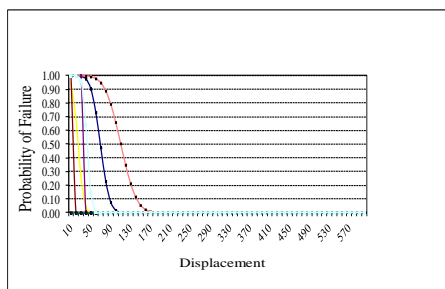

a)   For A soil class

b)   For B soil class

c)   For C soil class

Figure 22. The Y-direction fragility curves obtained taking into account the water effect for all soil classes.
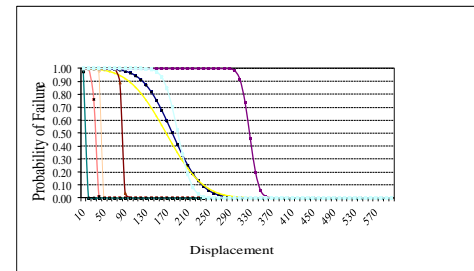
This order can be seen in the Fragility curves in Figures 19 to 22.
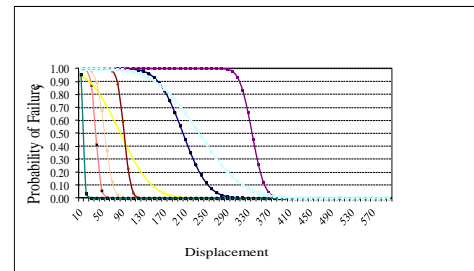
CONFLICT OF INTERESTS

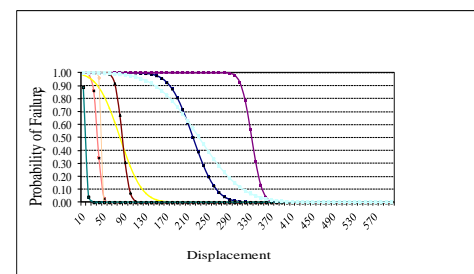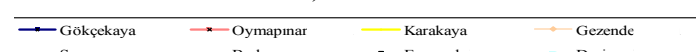The authors have not declared any conflict of interests.

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