Interdependence between Structural Engineering and Construction Management
Edited by Ozevin, D., Ataei, H., Modares, M., Gurgun, A., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-6-2

INVESTIGATION OF DAMAGE ON DERBENDIKHAN DAM DURING EARTHQUAKE EXCITATION

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In this study, the performance of a damaged dam was evaluated through a three-dimensional finite element model. The dam is located in Derbendikhan city of Northern Iraq and damaged during a 7.3 magnitude earthquake which was happened 30 kilometers south of Halabja city. Derbendikhan dam which was built between the years 1956-1961 is a clay-core rock fill dam. The damage of the dam was investigated at the site right after the earthquake and some cracks were observed in the main body of the dam. The main goal of this work is to present the results of the survey which was conducted at the site and investigating the damage development mechanism through a realistic three-dimensional finite element model of the dam. As complying with the observations at the site, the finite element analysis has shown that the primary failure mechanism is due to the separation of the core and rock fill sections at the downstream side of the dam.

Keywords: Damage development mechanism, Three-dimensional finite analysis, Google Earth, Mohr-Coulomb Model, Plastic analysis, Hydrodynamics.

1 INTRODUCTION

A 7.3 Mw earthquake occurred on 12.11.2017 with local time at 18:18:17 around the part of Bitlis-Zagros mountain range near the Iraq-Iran border, which is 30 Km south of Halabja province. A scientific team was formed from the members of Dicle University College of Engineering in order to investigate the effects of the earthquake on-site. The team, which included researchers Assist. Prof. Dr. M. Sefik Imamoglu from the Dept. of Geology of Mining Engineering, Assoc. Prof. Dr. Idris Bedirhanoglu from the Dept. of Structures of Civil Engineering, and CE Nihat Noyan from the Chamber of Civil Engineers/Diyarbakır branch, arrived at the earthquake affected region on 14.11.2017, and started investigations just after three days. Regions with significant damages were identified via consulting with the local authorities and examining earthquake records in Suleymaniyah Earthquake Center. Detailed reports on the earthquake, damage to the structures and geological aspects are covered in a field report (Bedirhanoglu and Imamoglu 2017), and also in two conference proceedings (Imamoglu *et al.* 2018, Bedirhanoglu *et al.* 2018). Eventually, the city of Derbendikhan and especially the dam near the city were found to sustain major damages. Thus, investigation efforts were first directed to the dam and later to the heavily damaged structures in Derbendikhan city. On-site investigation efforts on the dam revealed a large lateral crack at the top of the dam structure running through the entire width of the dam. The crack is on the downstream side and becomes wider as one moves towards to the center of the span of the dam. The crack indicates a suspected case of separation of the clay core and the surrounding rock-fill sections. In this study, a 3D finite element model with infinite boundary conditions and hydrodynamic effects is used to analyze the case. Mohr-Coulomb material model is used with characteristic values encountered in rock-filled clay core structures. Moreover, actual schematics of the structure are unavailable, so Google-Earth measurements and characteristic slope values with some information from a photo of the dam obtained from the site investigation, will be used to model the geometry of the dam. Nevertheless, it will be shown that observed damage is likely a result of the partial separation of core and surrounding filling.

2 DERBENDIKHAN DAM AND SURROUNDING AREA

Derbendikhan (Derbendixan) dam is located inside a narrow valley near Derbendikhan district along north-northeast direction (Figure 1). Derbendikhan district in turn is located at the near south of Suleymaniyah province. The 535 m long dam is constructed on a thick limestone layer which is split off deeply by the streams feeding the reservoir and which sits on an alternate formation of mudstone and silt stone. It was constructed between the years 1956-1961 as a rock fill dam with a clay impermeable core. It has a height of 128 m and has a reservoir capacity of 3 billion m^3 (Figure 1). Lack of information required to obtain data from open sources and as a result geometrical data were measured from Google Earth as seen in Figure 1 left side. The exact dimensions of the clay core are unknown and assumptions made on the slope and bottom width of the core sections.

Figure 1. Close-up view of Derbendikhan Dam view from right bank and geometrical dimensions.

3 EFFECT OF EARTHQUAKE ON DERBENDIKHAN DAM

The earthquake focused in this study occurred on 12.11.2007 at UTC 18:18:17 (21:18:17 local time) at 30 Km south of the city of Halabja, Suleymaniyah/Iraq on the Bitlis-Zagros rupture zone near Iraq-Iran border. The faults of the rupture zone caused an earthquake with a magnitude of 7.3 Mw. Due to the first announcement by USGS, the epicenter is located at 34.957°N 45.792°E with a depth of 25 km. Later the location is revised as farther to east 34.905°N 45.956°E and the depth is revised as 19 km. Thus the territorial address of the epicenter was shifted from Suleymaniyah/Iraq to Kermanshah/Iran. The earthquake was felt in a vast region and caused major damage to the dam structure. A prominent crack running through the span of the dam is visible on the crest of the dam as can be seen in Figure 2. This crack is on the downstream side and reaches up to 30 cm in the middle. Moreover, end cracks appeared on both sides of the dam.

These findings suggest rocking of the entire dam body along the stream direction and resulting separation of the core and filling sections. Also, a depression occurred on the downstream side of the crest.

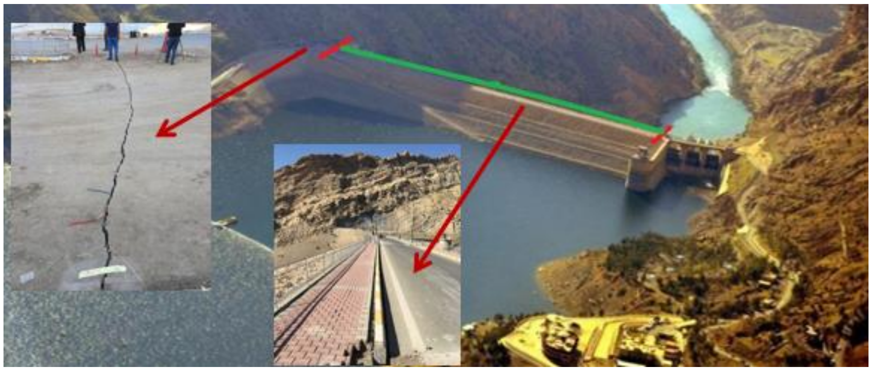

Figure 2. Lateral downstream crack (green) and end cracks (red) occurred on Derbendikhan dam structure during the earthquake.

4 FINITE ELEMENT MODEL

We analyzed the dam structure with static (dead weight, hydrostatic pressure) and dynamic (ground motion, hydrodynamic) loads. The model consisted of a 3D finite element model of the structure with Mohr-Coulomb plasticity. The exact dimensions of the dam structure, the clay core section, exact material parameters, water level during the earthquake and ground acceleration records were unable to obtain. Thus, a series of assumptions were made. Assumptions about the geometry were made partly due to the Google Earth measurements as indicated before (Figure 1) and assumptions on the material parameters were made due to characteristic values for the Mohr-Coulomb model. They are selected as in (Table 1) similar to given values in the literature (Ghafari *et al.* 2014).

Table 1. Material properties.

	E (Mpa)	ν	c (kPa)	φ	*φ*	ρ (kg/m³)
Clay core	40	0.32	80	26	0	1600
Rock fill	80	0.28	20	37	8	2000
Ground	3000	0.28	5	42	7	2250

Assumed dimensions are approximately taken from the Google Earth measurements (Figure 3). Thus base width of the model is 570 m and crest width is assumed to be 20 m. The dam is assumed to be holding a water level of 120 m during the earth quake. The clay core's base width is assumed to be 70 m. The slopes of the filling and the core are around 25° (slope ratio ≡ 1/2) and 79° (slope ratio ≡ 5/1) respectively.

4.1 Hydrodynamic Effects and Modeling Considerations

Hydrodynamic effects are taken into consideration via an approximate method. The analytical solution of pressure distribution over the downstream slope of a 2D rigid dam with a height of H under constant acceleration of a_0 can be given per Chwang (1978) in Eq. (1),

$$p = C_p \rho_w H a_0. \quad (1)$$

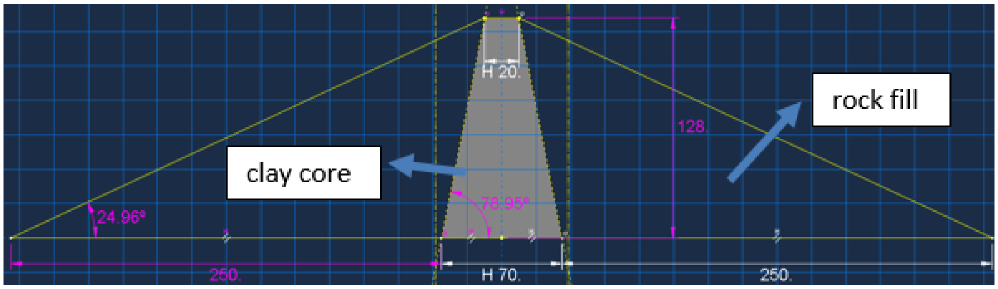

Figure 3. Assumed cross section for the Derbendikhan Dam used in the analysis.

Here C_p is the depth varying pressure coefficient (Figure 4) and ρ_w is the water mass density (1000 kg/m^3). In the assumption of the theory a certain portion of the water body moves with the dam thus an added associated mass is considered. In the analysis this contribution is considered over a thin section on the slope of the downstream side. The 120 m depth is divided into 10 equal sub-sections with a strip of 2.5 m wide. Each sub-section is then assigned with the average value of the increased density.

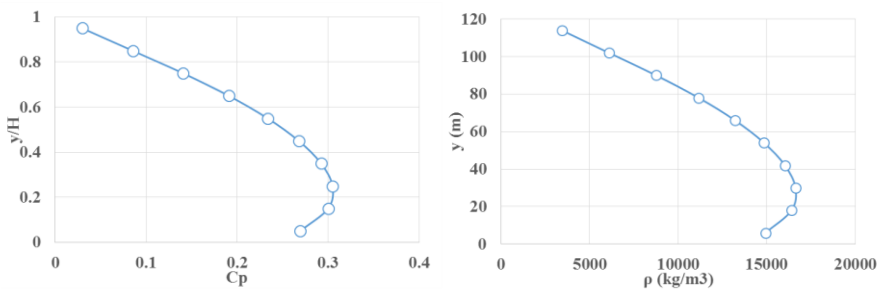

Figure 4. Variation of C_p Increased mass density due to hydrodynamic effects on downstream slope.

The body of the dam is modeled with 60039 C3D8R type 3D elements (Figure 5). Moreover, the ground and immediate surroundings are modeled with infinite elements in order to mitigate the effects of rigid boundary conditions (ABAQUS™ Analysis User Guide 2013). For this purpose 832 CIN3D8 type elements were used (green section in Figure 5). Out of plane dimensions are 535 m at the crest and 328 m at the base. Perfect bonding is considered between the dam body and the ground as well as between the rock-fill section and the clay core. Loads consist of the deadweight of the entire assembly with respect to the given densities in Table 1, hydrostatic water pressure on the downstream slope up to 120 m, hydrodynamic effects due to increased mass during the earthquake and finally the ground accelerations. As it was not possible to obtain the actual records ground accelerations are taken directly factorized (0.5) versions of the 1999 Kocaeli Earthquake whose components are shown in Figure 6. The load is applied in three steps with explicit dynamic analysis. In the first step, dead weight is applied due to self-weight of the dam structure only. In the second step hydrostatic pressure is superimposed over the first step. Finally in the third step ground acceleration is given. In the first and second steps, although explicit analysis is used, a quasi-static approach is taken and loads are linearly ramped to their final values with a total loading time of 400 secs.

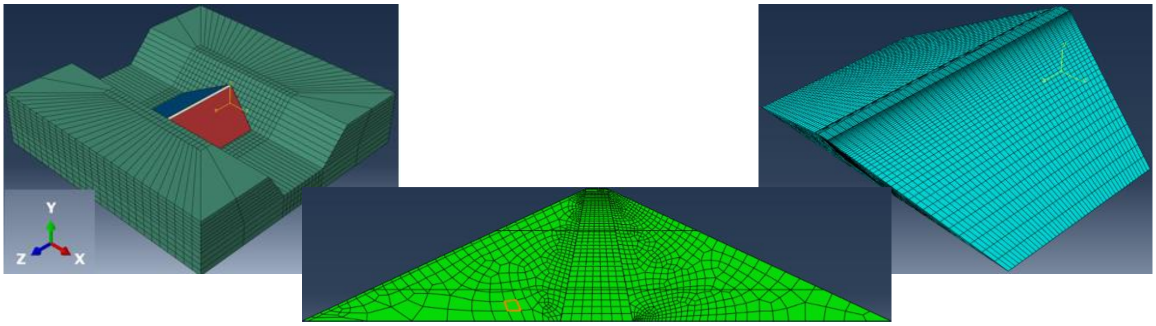

Figure 5. Complete dam assembly with the ground (infinite elements) and meshed dam cross-section and 3D body.

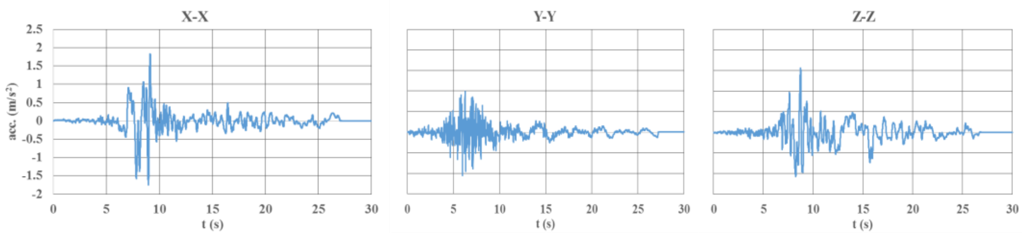

Figure 6. Components of ground acceleration used in the analysis.

5 RESULTS AND DISCUSSION

Analysis results are reasonable with the field observations (Figure 2). Figure 7 shows the vertical displacement field before (left) and after (right) the earthquake. It is seen that due to self-weight,

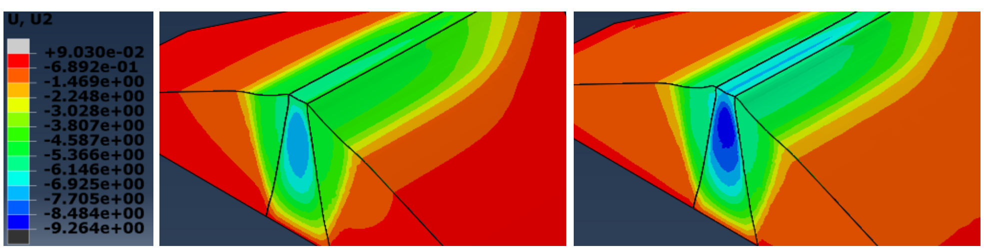

Figure 7. Vertical displacement (m) field before (left) and after the (right) earthquake.

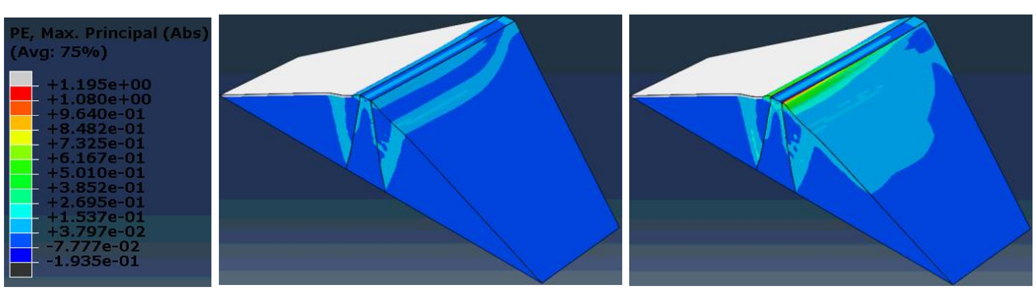

Figure 8. Absolute values of max principal plastic strains before (left) and after (right) earthquake.

consolidation type settling occurs and as observed in the field an additional depression around 1 m occurs around the crest region after the earthquake.

In plastic analysis, a measure of the concentration of max plastic strains can be assumed as probable fault (crack) zones. Figure 8 shows the absolute value of max plastic strains which also indicates the end slip bands which manifested as end cracks and the lateral downstream crack running along the length. Mohr-Coulomb material model seems to be reasonable when elaborate data on material parameters are not available. As it is seen that this simple nonlinear material model with assumed parameters and partly assumed dimensions are able to capture the observed damage mechanism. Thus we can conclude a possible separation of the core and rock fill sections which is prominent at the downstream side. The water pressure seems to limit the separation on the upstream side. Overall the damage mechanism fits with the on-site outer observations. Thus it can be concluded that the dam structure is non-negligibly damaged and care must be taken.

Acknowledgments

We deeply appreciate the support of Diyarbakir Branch of Chamber of Civil Engineers and its member Civil Engineer Nihat Noyan who took part in our investigation group; and Dicle University Physics Department's graduate student Mr. Qadri Ahmed Yusif who accompanied us with his vehicle and also acted as our translator and guide. We also thank Dr. Ramazan Hamza Muhammed from Duhok University, Department of Geology, and members of Duhok Seismology and Meteorology Institute; Head Dara Hasan Faraj, seismology Bakir M Saeed Ali, Aras Muhammed Tofig, Omid Muhammed Mahsun, Borhan İbrahim Salih for their companionship during the on-site investigations. We need to also mention the help of Union of Engineers Duhok Chamber members Abdul Emir and Diler Abo. We also want to thank Dicle University Engineering department and Dean of Engineering Faculty Prof. Dr. Abdullah Toprak, who made this site visit possible. Finally, we appreciate the financial support provided by MASAKA General Trading – Import and Export LTD Company, KRG, Iraq.

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