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Investigation of Leakage and Stability Analysis in Rock Filling Dams: The Example of Kolludere Pond

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ABSTRACT

Dams and ponds as engineering structures pose various risks during design, construction and operation. Deformation in dams, slope stability problems or excessive pore pressure can cause serious damage that cannot be prevented. It is critical to position these areas correctly and to evaluate the potential damage quantitatively. In rockfill dams, serious work needs to be done during the planning and project phase, especially on infiltration and slope safety. Otherwise, serious damages that cannot be prevented may occur in the dams. In this article, an example of rockfill dam type, infiltration and body stability analyzes of the 34 m high Kolludere Pond were calculated using the finite element method. The Geostudio program developed by the Geo-Slope company was used in the calculation of this analysis. For the analysis, the parameter values included in the field studies carried out with DSI were used. The dam body was modelled using parameter values and laboratory experiments. As a result of the modelling, whether the body of the pond remained in slope safety and the infiltration analysis results were evaluated.

1. INTRODUCTION

renewable energy types, has a large-scale distribution potential [1]. In the last thirty years, concrete faced rockfill dams have been widely used in large-scale hydroelectric projects due to their advantages such as low material cost, good adaptation to geological conditions and better performance under seismic loading conditions [2]. Hydroelectric energy reduces fossil fuel use, protects the environment and helps flood control [3]. A rockfill dam with a concrete face is an example of the dam type applicable for high dam design [4]. Concrete surface slab is the main component of the leak control system. Deformation, slope stability problems or excessive pore water pressure that may occur in dams can cause serious damage. This situation gives priority to dam safety in dam design [5]. Dynamic and static conditions should be considered together in the design and necessary safety precautions should be taken. The slope can be generally defined as "the horizontal mass that makes a certain angle with the existing land surface". The type, shape and land features of the body materials in the existing dams in our country differ. For this reason, there are differences in deformation, pore pressure and stability of each dam structure whose construction is completed. It is necessary to provide the necessary precautions by planning and project processes to be made before the construction phase of the dams against these problems that may occur during the operation process . The material parameters to be included in the dam structure should be analyzed by finding the required parameters as a result of the experimental applications. The basis of the parameters used in the numerical analysis method is based on the triaxial pressure test. The triaxial pressure test was performed only for the clay core. The clay core is modeled using an elastic-plastic model.

Another important analysis made in Embankment Dams is the seepage analysis. Infiltration is one of the important problems in dams. Seepage may cause internal erosion and tubing or dam collapse may occur as a result of slope stability shifts due to seepage pressures. The collapse rate that occurred as a result of the piping formed in the body of large embankment dams until 1986 was 32.5% [6]. This ratio increases more when taking into account the piping collapses in the foundation floor.

In the study, the Kolludere Pond, which is located within the borders of Baglar district of Diyarbakır province, about 15 km west of the province, on the Kodi stream, was modeled with the finite element method. Some of the parameters in the modeling were taken from the experiments made during the study phase. Determination of shear strength parameters of cylindrical rock exposed to triaxial compression is done with code. For some parameters, DSI embankment dams are modeled based on the design guide [7].

Dam Location and Characteristics

The Kolludere Pond is on the Kodi Stream, approximately 2250 m west of the Koldere Village. Kodi Stream's precipitation area in the pond area is 41.81 km² and the average elevation of the precipitation area is 1085 m. The irrigation area of the pond is 800 ha gross. Kolludere Pond was built in clay core rock fill type and for irrigation purposes. The height of the pond is 25 m from the thalweg, 34 m from the foundation, the body crest length is 2225.60 m, and the crest width is 8 m [8]. The reservoir volume of the dam has been determined as 1240593 m³ and the lake as 1708 km² (Fig. 1.).

Figure 1. Project Area on Earthquake Zones Map of Diyarbakır Province

Generally shallow and medium-depth earthquakes occur around the dam site. Region; Ministry of Public Works Disaster Affairs General Directorate, issued in 1996, and the Council of Ministers 18.04.1996 dated and 96/8109 decree in accordance with enacted "Turkey Earthquake Regions map" is located in the 2nd degree earthquake zone, according to the (Fig. 2).

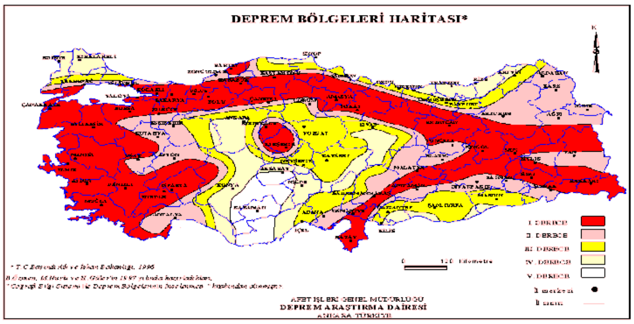

Figure 2. Turkey Earthquake Zones Map

2. MAIN TEXT

In this context, the effective ground acceleration coefficient is suggested to be between A0 = 0.40-0.30 g. However, according to the Kolludere Pond Seismic Hazard Analysis Report within the scope of the work, in the works carried out for "Diyarbakır-Central Kolludere Pond and Irrigation Project"; The maximum horizontal ground acceleration (PGA) found as a result of deterministic calculations was calculated as 0.065g. The OBE is calculated as 0.082g for the expected maximum horizontal ground motion acceleration (144-year return period) with the probability of exceeding 50% within the 100-year economic life calculated by probabilistic calculation [9]. It is recommended to take MDE = MCE = 0.141g and seismic design coefficient (k) = 0.10 for the expected maximum horizontal ground acceleration (475 years return period) with a probability of exceeding 10% within 50 years of the structure. (DSI, 2015) New maps, AFAD National Earthquake Research Program (UDAP) supported by Turkey "Updating the Seismic Hazard Maps" has been prepared under the project entitled Public and University Cooperation. (Fig. 3).

Figure 3. Turkey Earthquake Hazard Map (AFAD,2019)

The new map was created with much more detailed data, taking into account the most up-to-date earthquake source parameters, earthquake catalogs and new generation mathematical models. In the new map, unlike the previous map, the highest ground acceleration values are shown instead of earthquake risk zones and the concept of "earthquake risk zone" has been eliminated. The earthquake hazard map is not a risk map. In order to be a risk map, it is necessary to know the effects of the buildings and the population during an earthquake, to determine the economic losses, to calculate the damages that the earthquake will cause to the environment and to create a map showing the consequences of these damages and losses [10]. According to this new map, the maximum ground acceleration of the Kolludere Pond area and its surroundings should be around 0.1 g (Fig. 4.).

Each 16-dimension vector formed with four quads and this is where the quad processing unit name comes from. QPUs are arranged into groups of slices which share instruction cache, a special function unit, texture and memory lookup units and interpolation units. The QPUs are scheduled automatically by the VideoCore hardware with QPU scheduler. Raspberry Pi-3 contains 12 QPUs in its graphic engine. Each QPU has following key features:

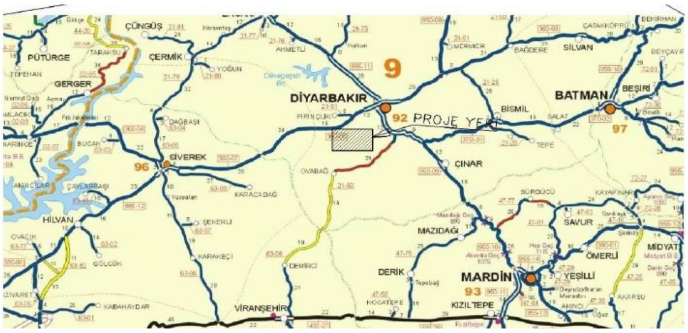

Figure 4. Kolludere Pond and Its Surroundings

In 2014, Broadcom Inc. announced to release of documentation for VideoCore IV and sources files for linux drivers under BSD license so that we were able to use the Video Core GPU as a very powerful parallel accelerator in our work.

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3. EXPERIMENTS

Two methods are commonly used in the stability analysis made by the finite element method. In the first method, gravity enhancement method, the gravity acceleration is increased until the slope collapses and the static state deteriorates [11]. In the second method, in the strength reduction method, c and ɸ are reduced until the slope migrates and the static situation deteriorates [12]. In this method, elasto-plastic analysis was made by taking different shear strength values obtained by dividing the shear strength parameters by a number of safety numbers. For the Mohr Coulomb material model, the shear strength reduced by the safety number (Fs) can be determined using Equation (1).

This relation

$$\frac{\tau}{Fs} = \frac{c}{Fs} + \frac{tan\phi}{Fs} \quad (1)$$

$$\frac{\tau}{Fs} = C^{*} + tan\phi^{*} \quad (2)$$

It can also be written as. In this case,

$$C^{*} = \frac{c}{Fs} \text{ ve } \emptyset^{*} = \arctan\left[\frac{tan\phi}{Fs}\right] \quad (3)$$

Shown in the figure. Here, c and ɸ are the shear strength parameters and c *, ɸ * are the reduced shear strength parameters.

Before designing dams and ponds, seepage and slope stability analyzes are the main issues that need to be studied. Before the hull slope analysis, some materials taken from the field are subjected to various tests in the laboratory environment. Especially in the field, the necessary parameters were determined by making a triaxial pressure test on the clay core material, and 7 boreholes (SK-1, SK-2, SK-3, SK-4, SK-5, SK-6, DSK-1) was opened and the properties and parameters of the ground were determined. It was investigated whether the bearing capacity of the soil was carried out by the Uniaxial Compressive Strength test, and whether the leakage of the dam floor where the body is located was within the intervals stipulated by DSI (Table 1).

Table 1. Boring Well Bst and Uniaxial Compressive Strength Test Results Taken at the Armdere Pond Construction Sites

Well No	Well Level (m)	Single Axis Pressure (kgf/cm²)	Bst (Lugeon)
SK-1	824.5	756	2.48
SK-2	820.5	719	2.58
SK-3	816	641	2.7
SK-4	801	714	2.55
SK-5	815	717	2.02
SK-6	824.5	689	3.18
DSK-1	798.4	769	2.53

Since the Kolludere Pond is built in the Rock Fill Dam type, the rock material to be used for the filling material will be provided from Karcadağ basalts, which are abundant in the Karacadağ Region. Rock Fill Dams mainly cut the direct contact of the water in the reservoir area of the dam or pond with the clay core, but adds more stability to the pond compared to earthfill dams. (Fig. 5.).

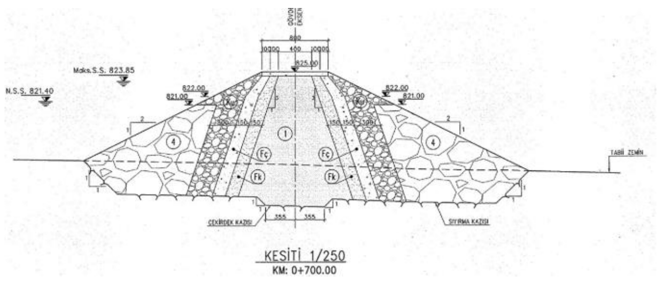

Figure 5. Kolludere Pond Body Cross Section

Analysis of slope stability according to the Kolludere pond project data will be made for 2 states. The situation was examined for the OBE and MDE earthquake situations before the impoundment, and the second case was examined for the OBE and MDE earthquake situations in the operational state where the impoundment of the dam was completed. According to the data in the project, the calculations and designs of the Kolludere Pond, which has not been completed yet, were made and it was investigated whether the slope status remained in the safe zone (Table 2.)

Table 2. Zone 1, Zone 2 and Filter Material Model and Final (average) Material Parameters (DSİ, 2015)

Malzeme	Permeability (K) m/s	Unit Volume Ağırlık (KN/m³)	Cohesion (C) Kpa	Internal Friction Angle (Φ)
Zone No.1	$3,4 \times 10^{-7}$	18	15	25
Zone No.2	$1,0 \times 10^{-5}$	25	0	45
Bedrock	2×10^{-5}	26	500.00	55.00
Filter Gravel	0.005	19	0	35
Filter Sand	0.005	19	0	35
Rocky	0,005	23	0	40

While performing slope analysis, Mohr-Coulomb shear circles method was used. Upstream and downstream slopes were evaluated and it was investigated whether the dam structure is located in the safe zone [13]. Another analysis of the Kolludere Pond is infiltration analysis. Seepage is a common problem, especially in rockfill dams. Concrete is manufactured on the front face of the rock fill in most projects to prevent leakage problem in rockfill dams. However, in the design of the Koldere Pond in question, the front face of the concrete was not designed. The infiltration event appears as a serious problem frequently encountered in dams and ponds, especially in operation. During the survey and field stage, it is necessary to obtain results with devices calibrated in the laboratory environment, especially for the materials taken in the field, and a good design should be created with the data obtained. Otherwise, the clay core, which provides pond impermeability, and the pond floor will cause serious problems, which we call piping. Due to the decrease in the amount of water pressure sent to irrigation in the reservoir area, which decreased as a result of the infiltration, the expected irrigation amount in the irrigation area foreseen as gross 800 ha may not be realized. Tubing causes increased pore water pressure inside the body, and has a negative effect on the stability of the body over time, affecting the body of the pond until it collapses. In short, the Infiltration and Slope

Stability Analysis is a situation that should be studied together.

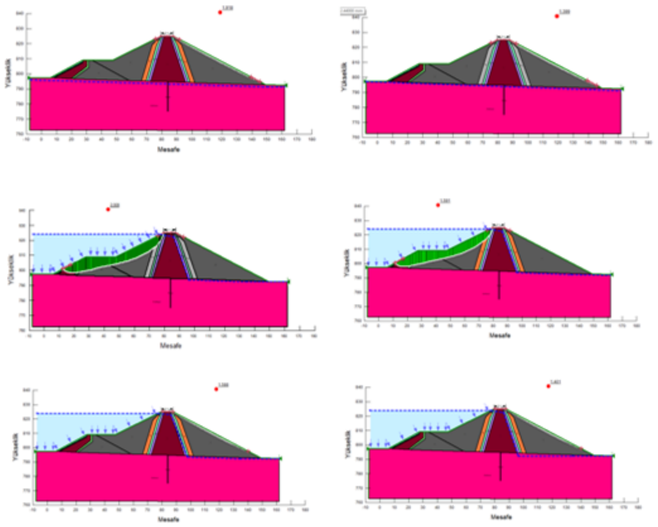

Figure 6. End of construction; Seismic and Earthquake, Operation Upstream OBE Earthquake and MDE Seismic, Operation Downstream OBE Seismic and MDE Seismic Slope Security Status

4. DISCISSION

Before the hull slope (stability) analysis, some materials taken from the field were subjected to various tests in the laboratory environment. Especially in the field, the necessary parameters were determined by making a triaxial pressure test on the clay core material, and 7 boreholes (SK-1, SK-2, SK-3, SK-4, SK-5, SK-6, DSK-1) was opened and the properties and parameters of the ground were determined. With the Single Axis Compressive Strength test, it was investigated whether the bearing strength of the soil and the Pressurized Water test value the leakage of the dam floor where the body is located is within the intervals prescribed by DSI. In the researches, it has been determined that the values measured by experiments are within the desired ranges.

Table 3. Kolludere Pond Safety Coefficients, Recommended Loading Conditions and Safety Coefficients (DSİ, 2012)

Status	Loading State	Safety Coefficient	Kolludere Pond Safety Coefficient
End of Construction	Unusual	1.3	1.92
End of construction Earthquake (OBE)	Extreme	>1.0	1.59
Operational	Usual	1.5	1.92
Operation Earthquake (OBE)	Unusual	1.2	1.59
Operation Earthquake (MDE)	Extreme	>1.0	1.40
Sudden Discharge	Unusual	1.2	2.59

The hull stability analysis was carried out to ensure that the upstream and downstream slopes are in the safe zone. As a result of the analysis, the said slope slopes and material parameters were evaluated together and the analysis was concluded. When the slope security situations in the table above are examined; End of construction downstream slope security status without earthquake 1,918, End of construction MDE earthquake downstream slope security number 1,399, post-construction OBE earthquake upstream slope security number 2,006, Operation MDE earthquake upstream slope security number 1,591, Operation MDE earthquake In the case of downstream OBE slope safety, the security number was 1.588, and in the case of Operation MDE earthquake downstream slope safety, the security number was 1.401 (Table 3.).

It has been observed that the stability values of the dam remain in the safe zone in each of the aforementioned cases. It has been concluded that the dam body will remain stable even in case of OBE (Operating Basis Earthquake) and MDE (Maximum Design Earthquake) seismic earthquakes (Fig. 6).

Seep analysis was carried out on the pond body. In this way, water flow lines, amount of leaking water per unit meter, equipotential curves and water pressure height values were determined. In the examination, it was determined that the water pressure heights in the body decreased from upstream to downstream (Fig. 7.).

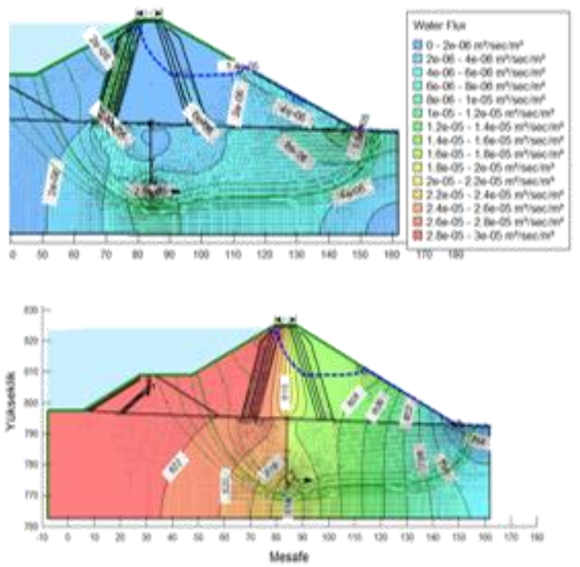

Figure 7. Leakage Analysis in Operational Status Amounts of Water Leaking per Unit Meter, Leakage Analysis Equipotential Curves and Water Pressure Head Distribution

In this way, it has been determined that the energy of the water pressure is broken while moving through the body of the pond. Another study is the analysis of the amount of water leaking per unit meter through the pond body of the rockfill-type Kolludere pond. The energy breaking of the water on the upstream side while passing through the body and the vertical water flow by increasing its speed while passing through the filter materials was directed towards the pond foundation and gathered around the injection curtain. Therefore, as a result of the analysis, the maximum leaking water amount per unit meter was determined as 2x10-5 m^3 / s just below the pond injection curtain. It has been determined that the maximum amount of water leaking per unit after the injection curtain passes through the filter materials on the upstream side and the parts located in the downstream heel of the pond body at 1.6 10-5 m^3 / s per second.

Symbols

Fs: Security Numberc: Kohezyon (KN/m²)

ф: Internal Friction Angle (◦)

c*: Reduced Cohesion (KN/m²)

ф*: Reduced Internal Friction Angle (◦)

E: Elasticity Module

REFERENCES

[1] Qu Y., Zou D. Seismic cracking evolution for anti-seepage face slabs in concrete faced rockfill dams based on cohesive zone model in explicit SBFEM-FEM frame. Soil Dynamics and Earthquake Engineering 2020; 133(1):106106

[2] Chen Y., Hu R., Modeling coupled processes of non-steady seepage flow and non-linear deformation for a concrete-faced rockfill dam. Computures and Structures 2011 pp 1333-1351 https://doi.org/10.1016/j.compstruc.2011.03.012

[3] Zarfl C, Lumsdon AE, Berlekamp J, et al. A global boom in hydropower dam construction. Aquat Sci 2015;77(1):161–70.

[4] Qu Y, et al. Seismic damage performance of the steel fiber reinforced face slab in the concrete-faced rockfill dam. Soil Dynam Earthq Eng 2019;119:320–30.

[5] Cernica J.N Geotechnical Engineering: Soil Mechanics, John Wiley and Sons Inc., Canada 1995.

[6] Sağlıca, 2013 Leakage Analysis of Embankment Dam Bodies, Master's Thesis, University Gazi, Ankara, 85 p.

[7] Ministry of Forestry and Water Affairs, General Directorate of State Hydraulic Works, 1st Dams Congress, Embankment Dams Design Guide October, 2012 Ankara p, 1-151

[8] Devlet Su işleri, DSİ, 2015 Kolludere Pond, Planning Report

[9] Devlet Su işleri, DSİ, 2015 Kolludere Pond, Geotechnical Report

[10] AFAD, 2019, https://deprem.afad.gov.tr/ earthquake-hazard-map Internet Resource

[11] Chen, W. F. ve Mizuno, E., Nonlinear Analyses in Soil Mechanics: Theory and Implementation, Elsevier, Amsterdam, 1990.

[12] Zienkiewicz, O.C. ve Taylor, R. L., The Element Method, Vol. 1, 4thEdition, Mc Hill, New York, 1989.

[13] Zorluer ve ark. 2018 Investigation of Dam Leakage and Slope Stability Analysis: The Case of Kızık Dam, 5th International Dam Safety Symposium, 27 October-1 November 2018, İstanbul

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